Water Quality Modeling Report
for
Floyds Fork, Kentucky

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Revision History

The following table presents the revision history of the Floyds Fork Water Quality Modeling Report.

Table i-1 Revision History of Floyds Fork Modeling Report

Revision Number	Release Date	Comments
0	May 15, 2012	Initial Release of Report. Hydrology, Temperature/DO, Sediment, Water Quality, pH and Chlorophyll-a Calibration/Validation.
1	August 30, 2012	Added Springs in the model. Made minor text changes to document. Updated watershed inputs into model. Updated the water quality calibration.

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GLOSSARY OF TERMS

BOD_5: 5-day Biochemical Oxygen Demand. It is the amount of oxygen utilized by the microorganisms in breaking down the waste.

CBOD: Carbonaceous biochemical oxygen demand.

CHLA: Chlorophyll-a. It is a common type of chlorophyll present in all oxygen evolving photosynthetic organisms.

CSOs: Combined Sewer Overflows. It contains stormwater in addition to untreated human and industrial waste. There were no reported CSOs to be used in the Floyds Fork watershed model.

DMR: Discharge Monitoring Report. It is a United States regulatory for a periodic water pollution report produced by industries, municipalities and other facilities discharging to surface waters.

DO: Dissolved Oxygen. It is the measured oxygen in its dissolved form.

DOS: Disk Operating system.

USEPA/EPA: Environmental Protection Agency. This organization is a federal agency responsible for protecting human health and the environment, by enforcing regulations based on laws passed by Congress.

EUTRO: It is a special kinetic subroutine in WASP that represents conventional water quality processes.

HSPF: Hydrologic Simulation Program FORTRAN. It is used for simulation of watershed hydrology and water quality for both conventional and toxic organic pollutants.

HTRCH: It is a subroutine in HSPF/LSPC that simulates heat exchange and water temperature.

HUC: Hydrologic Unit Code. It is a watershed identifier. This is a standardized watershed classification system developed by United States Geological Survey.

KDOW: Kentucky Division of Water. This organization is responsible for protecting, managing and enhancing the quality of the Commonwealth’s water resources through voluntary, regulatory and educational programs.

KPDES: Kentucky Pollutant Discharge Elimination System. As authorized by Clean Water Act, KPDES permit program is responsible for controlling water pollution by regulating point sources that discharge pollutants into Kentucky waters. 73 KPDES facilities were identified and used in the Floyds Fork model.

LSPC: Loading Simulation Program in C++. It is a watershed modeling system that includes streamlined HSPF algorithms for simulating hydrology, sediment and general water quality on land as well as a simplified stream transport model. This modeling system was used for the Floyds Fork watershed model.

MGD: Million Gallons per Day. This is the unit used by most of the agencies to report flows/overflows.

MOVEM: It is the graphical post processor in WASP to process the simulation result files.

MSD: Municipal Sewer District. It is a non-profit regional utility service. It is responsible for the operation and maintenance of Louisville's combined sanitary and storm sewer system and sanitary-only sewer system. Part of the water quality data, information on CSO's and SSO's used in the Floyds Fork model was obtained from MSD.

NCDC: National Climate Data Center. It is the world's largest active archive of weather data. Weather data for Floyds Fork model was obtained from this agency.

NHD: National Hydrography Dataset. It is the surface water component of the National map. The NHD is a digital vector dataset used by GIS. This data is designed to be used in surface water systems. The sub-watersheds for the Floyds Fork model were developed using the NHD catchment data layer (1:100,000) that was obtained from the United States Geological Survey (USGS).

NH_3: Ammonia.

NOX/NO2+NO3: Nitrite-Nitrate.

NPDES: National Pollutant Discharge Elimination System. It is a permit program that controls water pollution by regulating point sources that discharge pollutants into waters of United States.

ORGN: Organic Nitrogen.

ORGP: Organic Phosphorus.

EPA PCS: Environmental Protection Agency's Permit Compliance System. It is a national computerized management information system that automates the NPDES/KPDES data. It was used to retrieve information on the NPDES/KPDES permits for the Floyds Fork model.

PCB: Polychlorinated biphenyl.

PERO: The subwatershed overland flow is designated as PERO in LSPC. It is the sum of surface, interflow and groundwater outflow volume for an individual subwatershed.

PO_4: Orthophosphate.

PSTEMP: This subroutine simulates soil temperatures for the surface, upper and lower layers of a land segment.

RO: The in-stream flow is designated as RO in LSPC. It is the total rate of outflow from all the reaches contributing to the downstream subwatershed.

SA: Surface Airways. NCDC Surface Airways contains hourly weather observations from the meteorological stations used in this model.

SOD: Summary of the Day. NCDC Summary of the Day contains daily weather observations from the meteorological stations used in this model.

SOD: Sediment Oxygen Demand. It is the sum of all biological and chemical processes in sediment that utilize oxygen.

SSO’s: Sanitary Sewer Overflows. They are occasional, yet unintentional discharges of raw sewage from municipal sanitary sewers. SSO’s from 27 NPDES facilities were identified for this model.

TKN: Total Kjehldahl Nitrogen. It is the combination of organically bound Nitrogen and Ammonia in wastewater.

TN: Total Nitrogen.

TOXI: It is a special kinetic subroutine in WASP that represents toxicants.

TP: Total Phosphorus.

TSS: Total Suspended Solids.

USGS: United States Geological Survey. It is a science organization that provides reliable scientific information to describe and understand the Earth and enhances and protects the quality of life.

WASP: Water Quality Analysis and Simulation Program. It is a dynamic compartment-modeling program for aquatic systems, simulating one-dimensional, two-dimensional, and three-dimensional systems, and a variety of pollutants.

WQTC: Water Quality Treatment Center.

WRDB: Water Resources DataBase. It is a comprehensive data storage system capable of handling a vast amount of data, accommodating a wide variety of data types and presenting data conveniently and efficiently.

WTEMP: Water Temperature.

1.0 INTRODUCTION

Floyds Fork lies in two 10-digit HUC watersheds, Upper Floyds Fork (HUC 0514010208) and the Lower Floyds Fork (HUC 0514010210) watershed in northwestern Kentucky, approximately 10 miles northeast of the city of Louisville. Ranging 62 miles in length, Floyds Fork originates in the southwestern portion of Henry County and flows southwest to unite with the Salt River in Bullitt County which then flows into Ohio River. Floyds Fork is a major tributary of the Salt River. Its drainage area is 285 sq. miles and is within the Salt River basin covering a significant part of central Kentucky. A total of 6 counties (Bullitt, Henry, Jefferson, Oldham, Shelby and Spencer) are located partially in the Floyds Fork watershed, thus making the watershed very important to a wide-range of communities. Figure 1-1 shows the location of Floyds Fork and Figure 1-2 shows Floyds Fork, the Floyds Fork watershed, surrounding counties and other features of the watershed. This report documents the development and calibration of the in-stream water quality model that will be used to predict the changes in water quality within Floyds Fork and its tributaries.

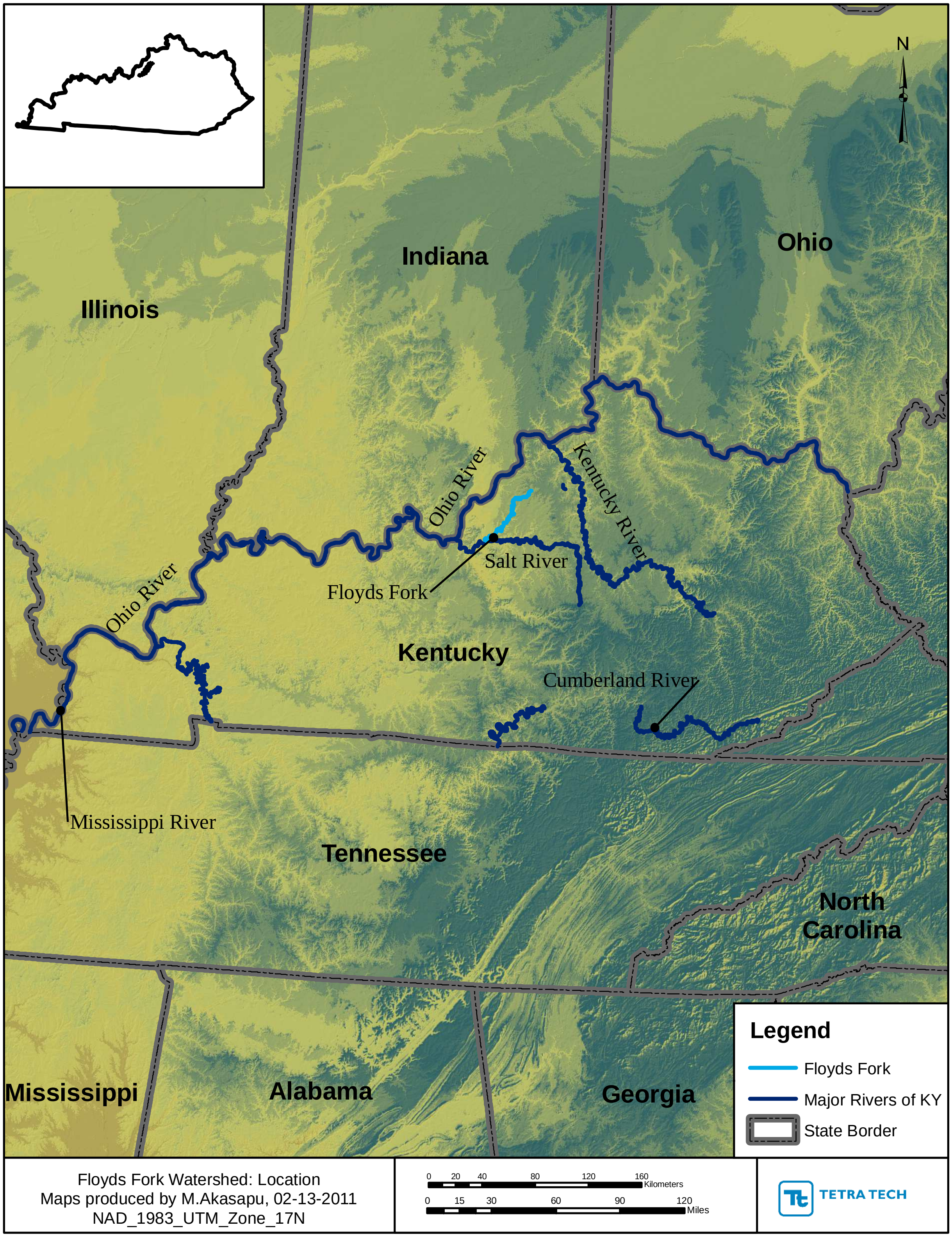

Figure 1-1 Location of Floyds Fork

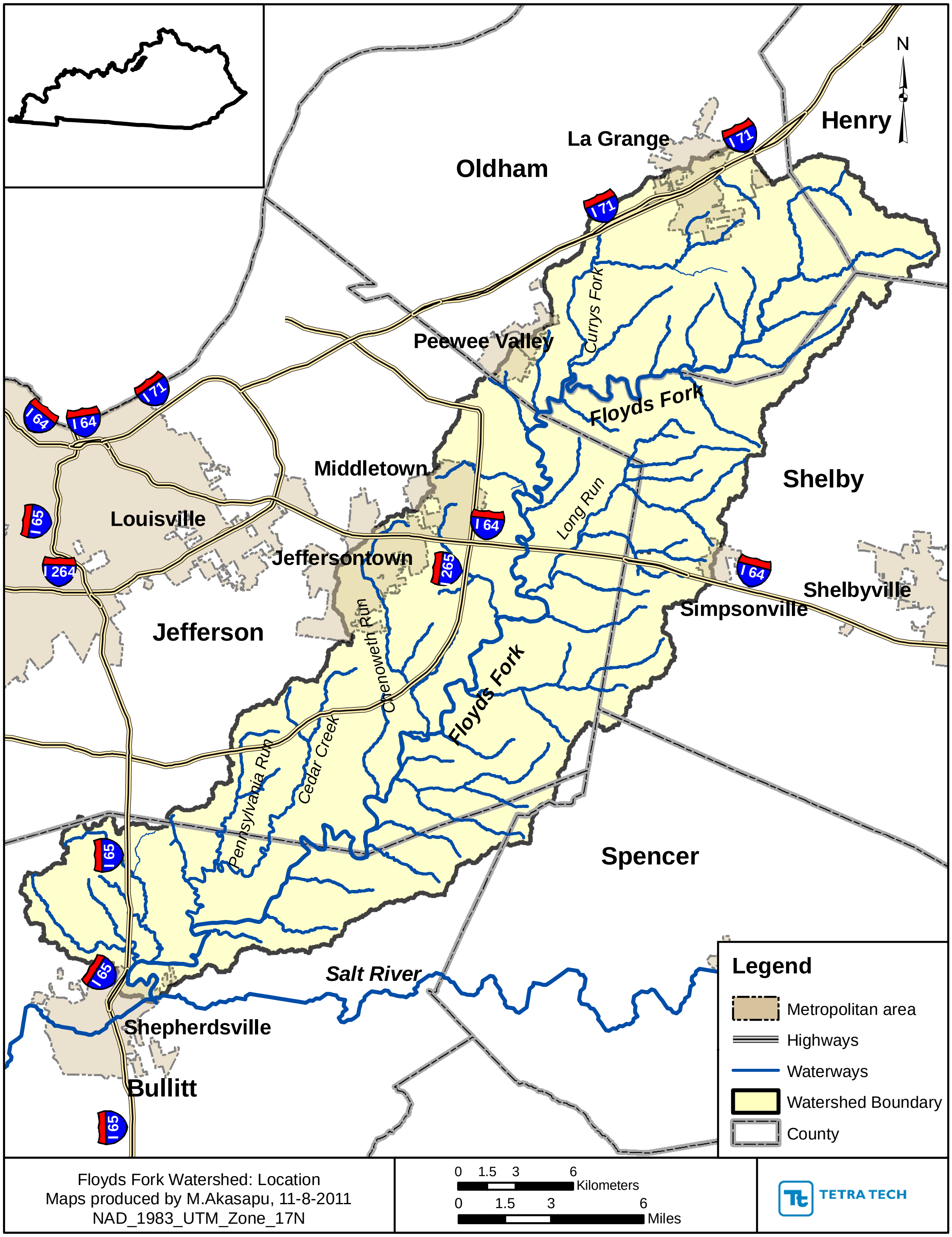

Figure 1-2 Floyds Fork Watershed

2.0 MODEL SELECTION AND BACKGROUND

2.1 WASP Water Quality Model

To address the nutrient loadings and the water quality standards for chlorophyll-a and dissolved oxygen, an in-stream water quality model was developed. The Water Quality Analysis Simulation Program (WASP 7.3) was utilized as the water quality model. WASP is a dynamic compartment-modeling program for aquatic systems, simulating one-dimensional, two-dimensional, and three-dimensional systems, and a variety of pollutants. It is capable of simulating four classes of algae (three free floating and one benthic algae class), sediment-water oxygen, pH/alkalinity and nutrient exchanges. The time-varying processes of advection, dispersion, point and diffuse mass loading, and boundary exchange are represented in the basic program. Water quality processes are represented in special kinetic subroutines that are either chosen from a library or written by the user.

WASP7 is the new version of WASP with many upgrades to the user's interface and the model's capabilities. The major upgrades to WASP have been the addition of multiple BOD components, addition of sediment diagenesis routines, and addition of periphyton routines. The Windows version of WASP7 has been developed to aid modelers in the implementation of WASP. With the new WASP7, model execution can be performed up to ten times faster than the previous United States Environmental Protection Agency's (USEPA) DOS version of WASP. Nonetheless, WASP7 uses the same algorithms to solve water quality problems as those used in the DOS version of WASP. WASP7 contains 1) a user-friendly Windows-based interface, 2) a pre-processor to assist modelers in the processing of data into a format that can be used in WASP7, 3) high-speed WASP eutrophication and organic chemical model processors, and 4) a graphical postprocessor (MOVEM) for the viewing of WASP7 results and comparison to observed field data.

WASP is structured to permit easy substitution of kinetic subroutines into the overall package to form problem-specific models. WASP comes with two such models: TOXI for toxicants and EUTRO for conventional water quality. Earlier versions of WASP have been used to examine eutrophication of Tampa Bay; phosphorus loading to Lake Okeechobee; eutrophication of the Neuse River and estuary; eutrophication and PCB pollution of the Great Lakes (Thomann, 1975; Thomann et al., 1976; Thomann et al, 1979; Di Toro and Connolly, 1980), eutrophication of the Potomac Estuary (Thomann and Fitzpatrick, 1982), kepone pollution of the James River Estuary (O'Connor et al., 1983), volatile organic pollution of the Delaware Estuary (Ambrose, 1987), and heavy metal pollution of the Deep River, North Carolina (JRB, 1984). In addition to these, numerous applications are listed in Di Toro et al., 1983. Figure 2-1 shows a diagram for the water quality model used in this application.

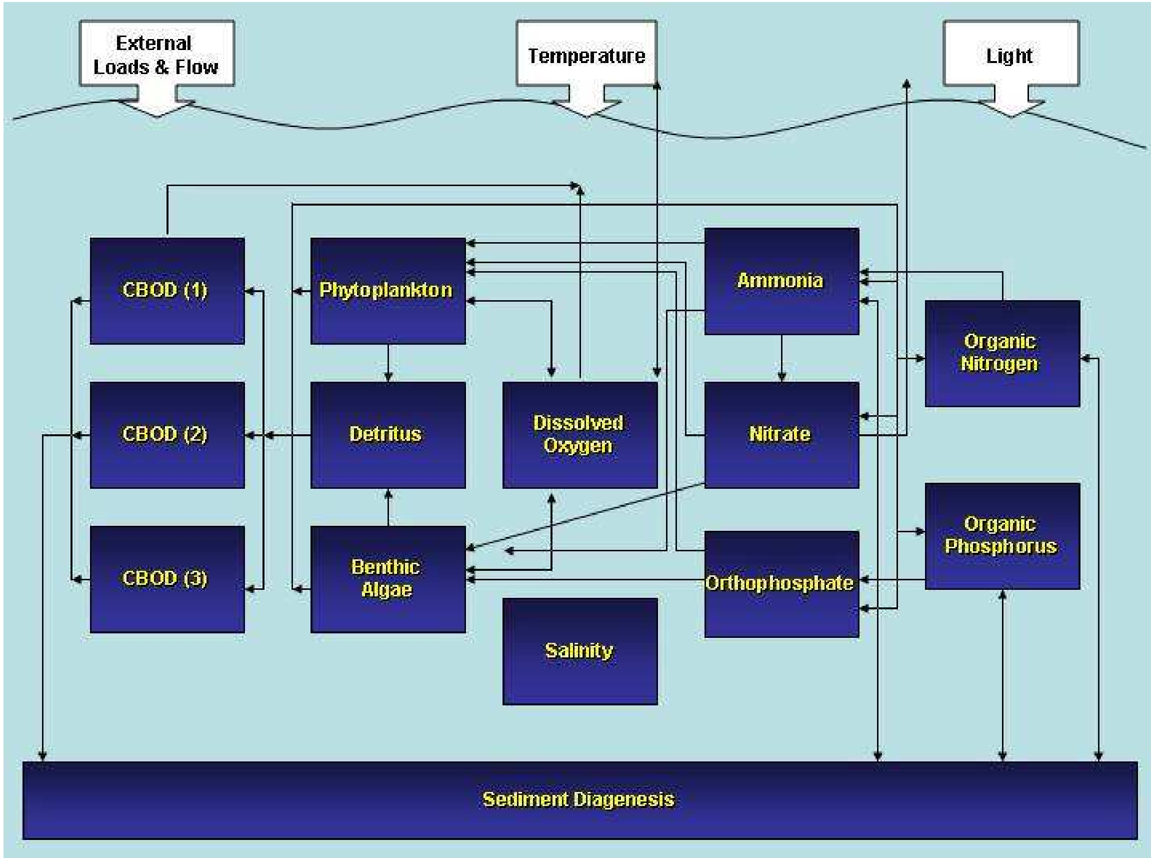

Figure 2-1 Water Quality Diagram for WASP

2.2 Integration of LSPC with WASP

To represent the flows and water quality concentrations coming into Floyds Fork and its tributaries, a separate watershed model was developed. This watershed model, the Loading Simulation Program C++ (LSPC), is capable of representing loading, both flow and water quality, from point and non-point sources. The setup and calibration of the LSPC model is described in detail in the report titled “Watershed Hydrology and Water Quality Modeling Report for Floyds Fork, Kentucky – REV 4” (Tetra Tech 2012). A brief summary of some key features in the watershed model are presented below.

The LSPC watershed model incorporated 73 NPDES point source discharges out of which 33 facilities had monthly/daily effluent monitoring data. For the facilities with no reported data, default concentrations were developed based on the influent concentrations, average percent removal of nitrogen and phosphorus and the ratios for nitrogen and phosphorus using the in-stream water quality data. The loads from point sources were input directly into the LSPC model as monthly time-series from 2000 through 2010. However, nine out of the 73 facilities were input as monthly average time-series from 2001 through 2007 and daily time-series from 2008 through 2010 and in some cases from 2007 through 2010.

In addition to the 73 NPDES point source discharges, the watershed model also utilized overflow data from 27 SSO’s and water withdrawal from 11 industrial facilities. Unlike the point source discharges, the reported discharge amount for the SSOs was input into the watershed model as daily time-series. To develop daily time-series inputs for SSO loads, published concentrations for typical composition of untreated domestic wastewater of medium or weak strength was used based on the impact observed at the facilities.

Septic tanks were represented as either failing or non-failing in the watershed model. It was assumed that 80% of the septic tanks in the all counties except Oldham, and 70% in Oldham County were working properly. The failing septics were modeled as a landuse and the non-failing septics was input into the model as monthly time-series.

Groundwater springs identified by USGS in the Floyds Fork watershed were also input into the watershed model. There are a total of 20 springs in the model. The flow and groundwater concentration for these springs were input directly into the LSPC model as time-series from 2000 to 2010.

All the techniques applied in developing the time-series for NPDES facilities, SSO’s, water withdrawals, non-failing septic systems and springs,are discussed in detail in the watershed report (Tetra Tech 2012).

Flow data collected at 7 USGS stations located in the Floyds Fork watershed were used to calibrate and validate the LSPC watershed hydrology model. Five of these stations were used as calibration stations and the remaining two were used as validation stations. The LSPC watershed model was calibrated from January 2001 through December 2010. Based on the hydrology calibration of Floyds Fork as presented in the report, the simulated flows were in close range with the observed flows.

The LSPC watershed model was also used to represent the accumulation and washoff of nutrients within the entire Floyds Fork drainage area. The LSPC model was calibrated and validated for temperature, dissolved oxygen, BOD_5, total nitrogen, total phosphorus and total suspended sediment. using observed data that were collected at 26 USGS calibration and 5 MSD validation stations throughout the Floyds Fork watershed.

Once calibrated, LSPC was linked to the in-stream water quality model (WASP) by providing flows and concentrations at tributaries and local drainage areas to simulate inflow to Floyds Fork for the 10-year simulation period - from January 1, 2001 through December 31, 2010. The watershed flows were an important input for the flow balance of the stream. It is important to note that although the LSPC watershed model was calibrated with NPDES facilities, SSO’s, water withdrawals, non-failing septic systems and springs, these were removed from the LSPC model prior to being linked to the WASP model. This was to insure that only the landuse contribution from the LSPC model was being input into the WASP model. The NPDES facilities, SSO’s, water withdrawals, non-failing septic systems and springs were direct inputs into the WASP model and are described further in Section 4.

3.0 DATA COMPILATION

Data needed for the calibration and validation of the WASP water quality model was obtained from several sources including the Kentucky Division of Water (KDOW), United States Geological Survey (USGS), Environmental Protection Agency (USEPA), and the Louisville and Jefferson County Metropolitan Sewer District (MSD). These data were needed, but not limited to: the model segmentation, point source inputs, water withdrawal inputs, watershed calibration and validation stations, water quality calibration and validation stations.

Table 3-1 Data Sources for Floyds Fork Modeling Effort

Data Source	Data Type
Kentucky Division of Water (KDOW)	Point Source Discharge Water Withdrawals Incident and Facility reports on Sanitary Sewer Overflows Water Quality Sampling Stations Chlorophyll-a data
United States Environmental Protection Agency – Region 4 (USEPA)	Point Source Discharge
National Climatic Data Center (NCDC)	Meteorological Data
United States Geological Survey (USGS)	Water Quality Sampling Stations Gaged Stream Flows Water Quality data
Louisville and Jefferson County Metropolitan Sewer District (MSD)	Water Quality data
Project WIN website	DMR reports on Sanitary Sewer Overflows

4.0 WATER QUALITY MODEL DEVELOPMENT

4.1 Overview

The WASP water quality model represents the variability of point and non-point source contributions through dynamic representation of in-stream processes. The WASP model includes contributions from all known point and non-point sources. Key components for the development of the water quality model include:

- Model Segmentation (Section 4.2)
- Simulation Period (Section 4.3)
- Meteorological Data (Section 4.4)
- Flow and Water Quality Boundary Conditions (Section 4.5)
- Sediment Oxygen Demand (Section 4.6)
- Nutrient Fluxes (Section 4.7)
- Rates and Constants (Section 4.8)
- Confirming Linkage of LSPC to WASP (Section 4.9)

4.2 Model Segmentation

For the WASP model segmentation, Floyds Fork and the tributaries to be simulated were divided into a series of computational segments. These segments are the discrete physical components where WASP solves its set of equations. The NHDPlus Flowline coverage was utilized to identify the selected waterbodies. Once the waterbodies to be modeled were selected, a maximum and minimum travel time of 0.296 and 0.016 days (7.10 to 0.38 hours) respectively was specified to divide the waterbody into segments of desirable length.

After the segments were created, a few segments needed to be added manually, as these segments were not included in the NHDPlus Flowline coverage but were included in the LSPC watershed model. In addition, some segments were divided or aggregated based on the location of the point sources, flow and water quality calibration stations.

Figure 4-1 shows the 212 model segments created for the WASP water quality model. Figures 4-2 through 4-4 present the Floyds Fork watershed divided into three sections, top, middle and bottom, respectively. These figures help to examine clearly the locations of the LSPC subwatersheds, point sources and SSO’s, and the flow and water quality calibration stations with respect to the WASP segments.

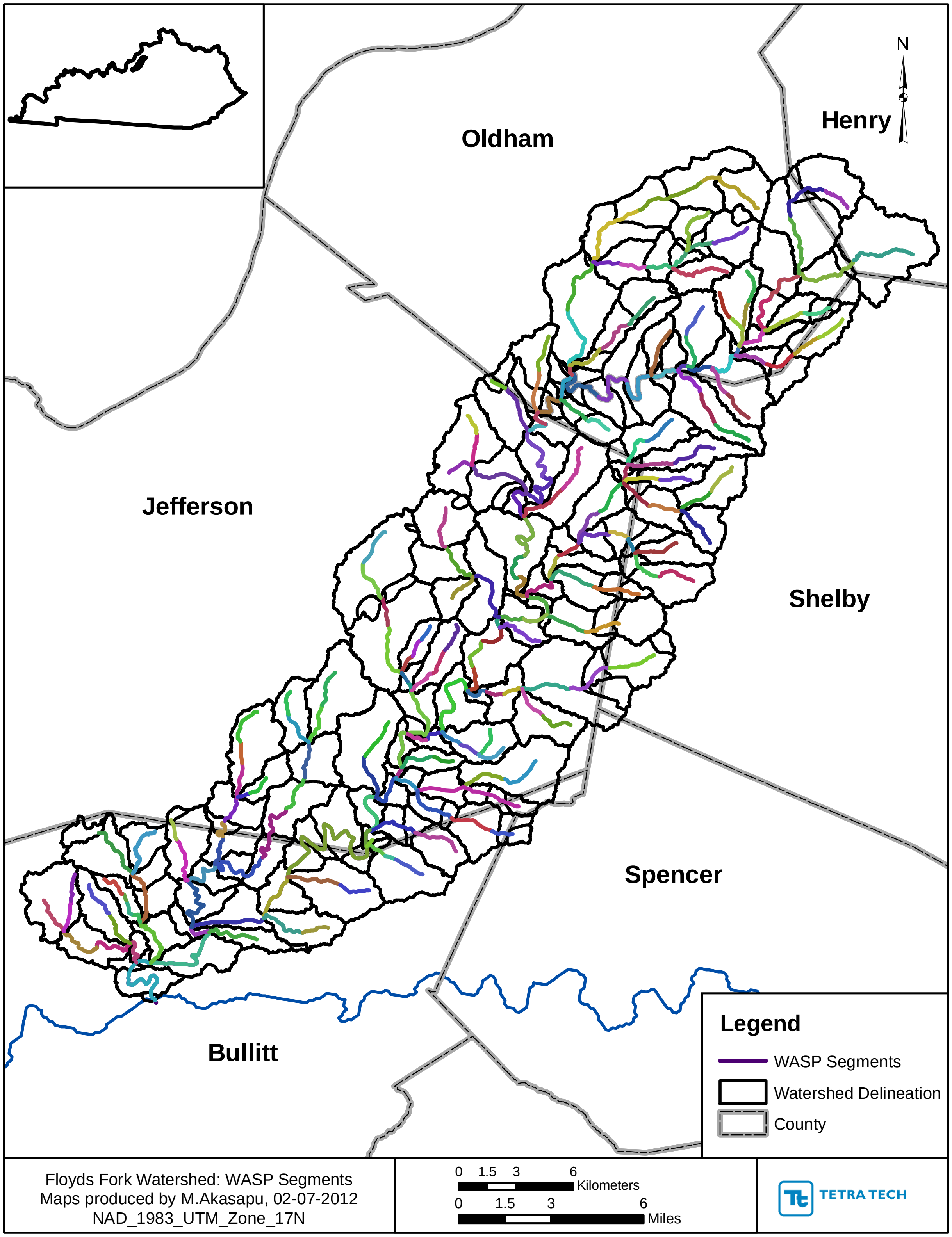

Figure 4-1 WASP Segmentation

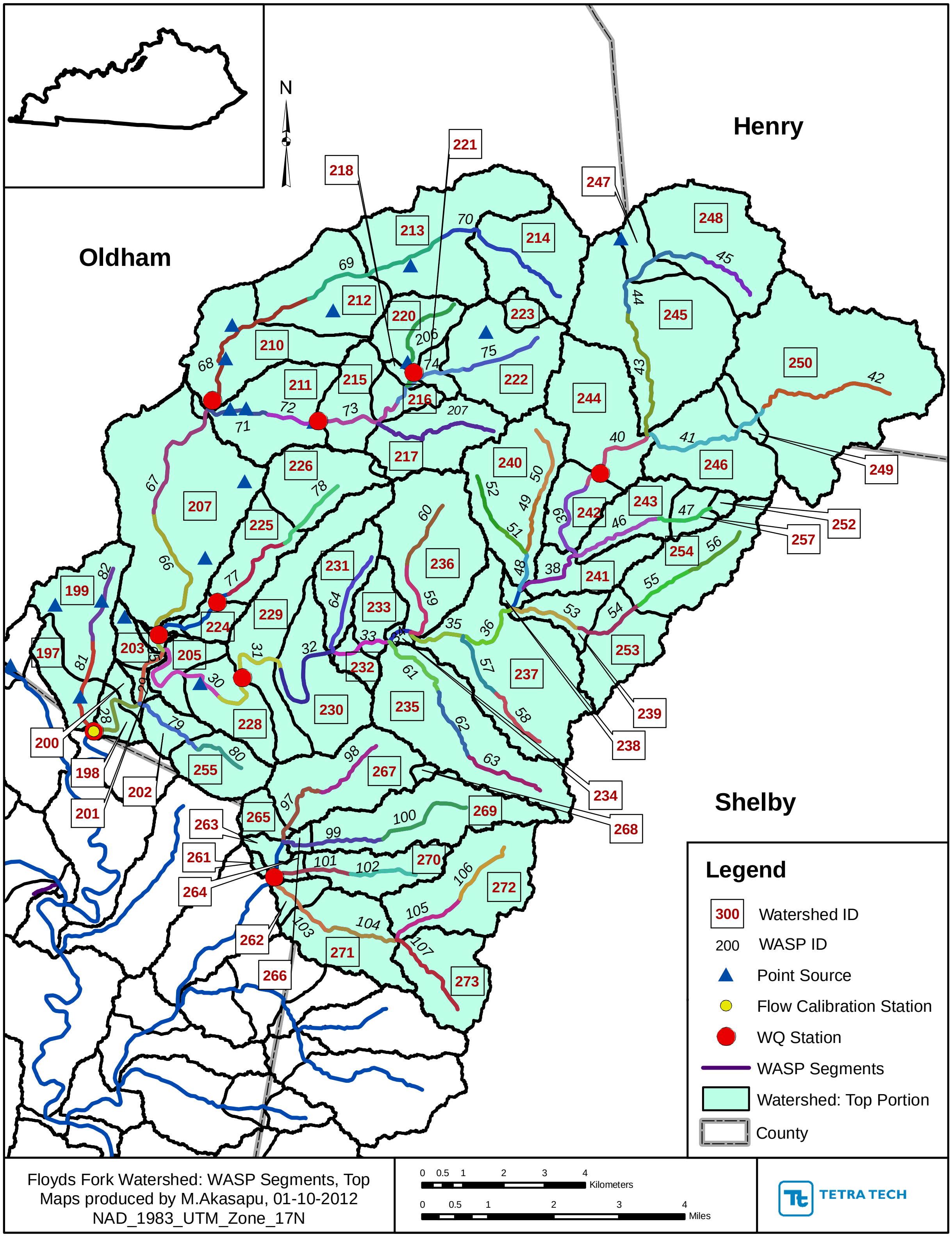

Figure 4-2 WASP Segmentation: Top Portion of the Watershed

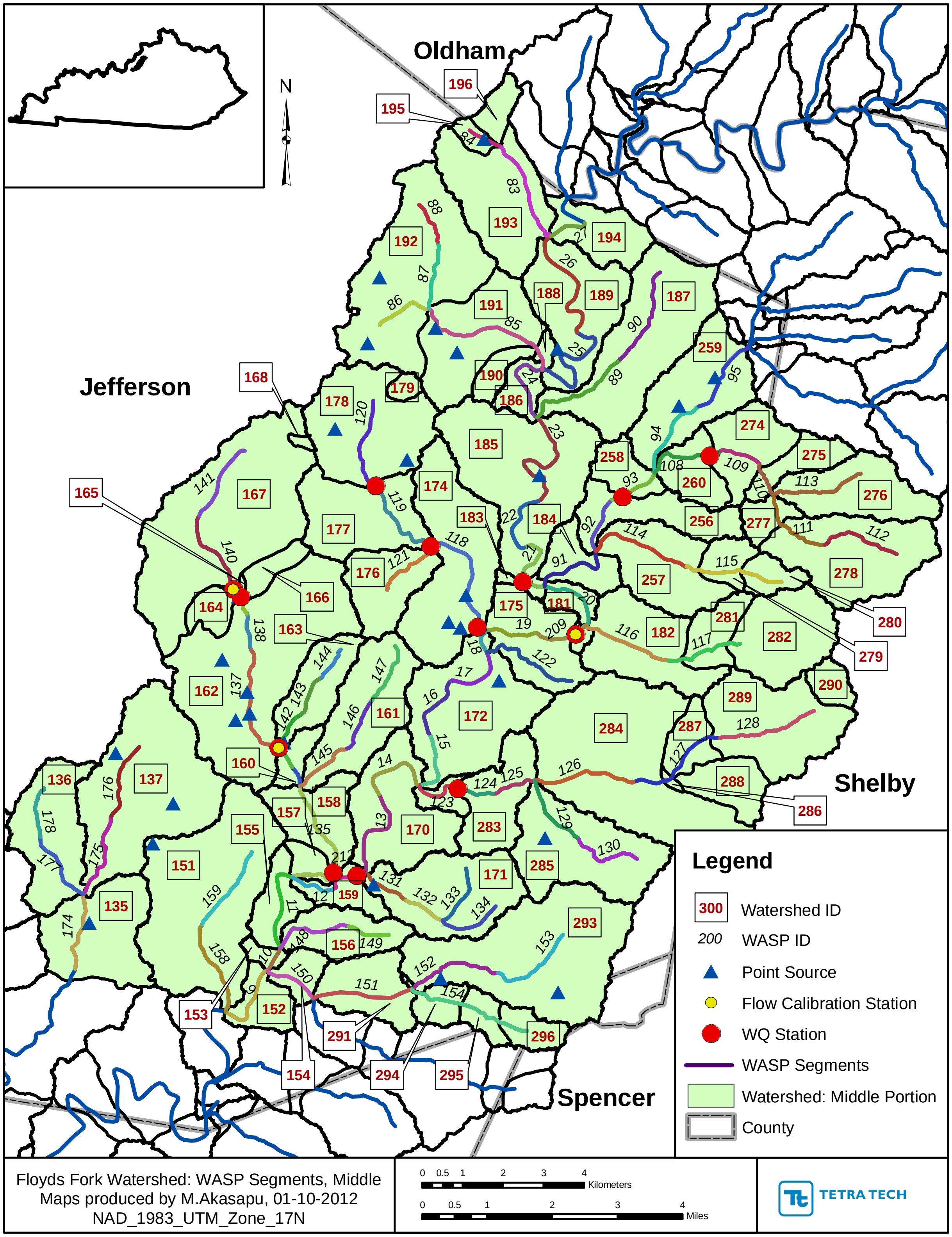

Figure 4-3 WASP Segmentation: Middle Portion of the Watershed

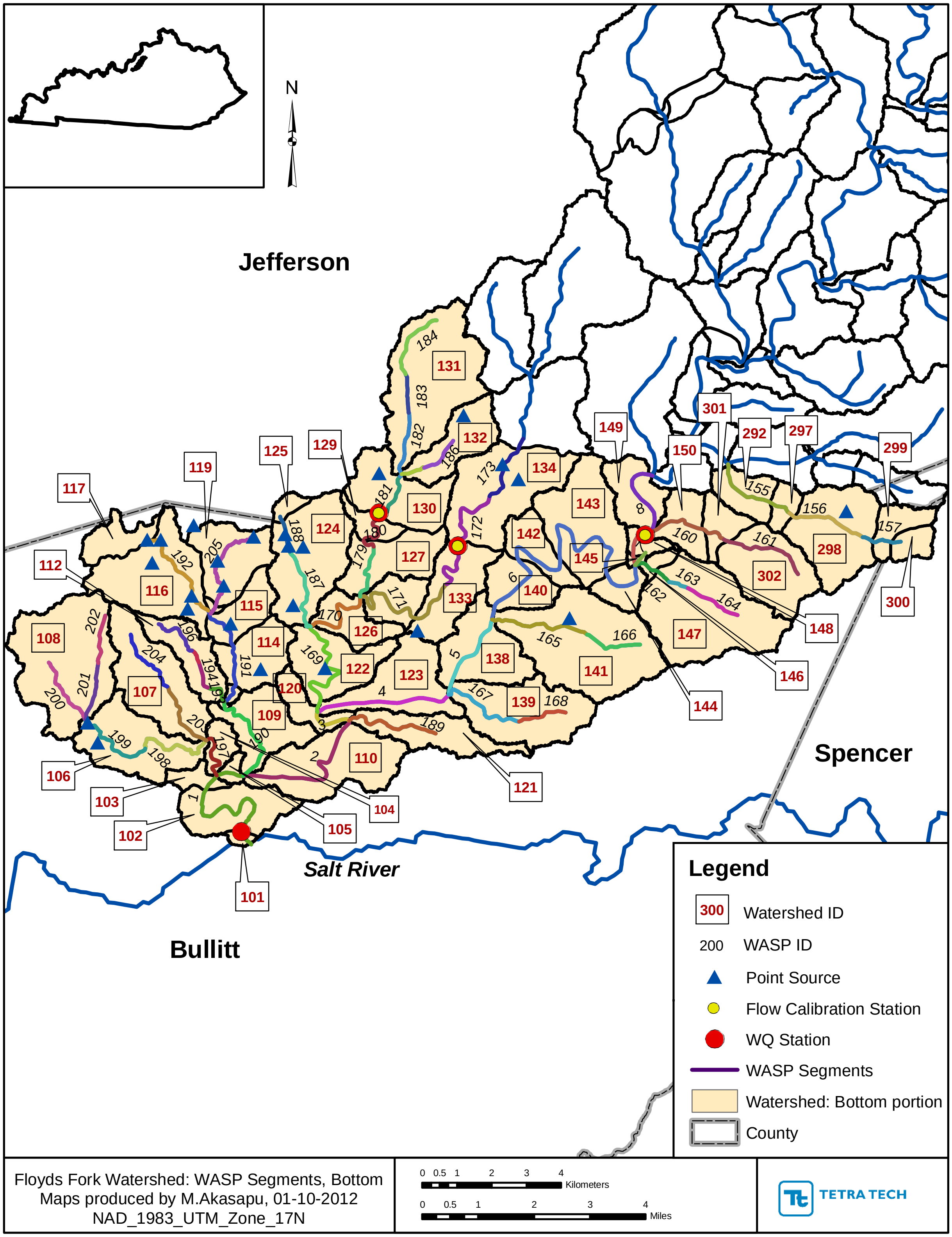

Figure 4-4 WASP Segmentation: Bottom Portion of the Watershed

4.3 Simulation Period

The WASP water quality model was simulated for the 10-year period from January 1, 2001 through December 31, 2010. This time period was selected due to the difficulty of acquiring complete data sets prior to 2001. This time period captured wet, drought and normal years.

4.4 Meteorological Data

Three meteorological stations were used in the calibration of the Floyds Fork LSPC watershed model (Tetra Tech 2012). These three stations were National Climate Data Center (NCDC) Summary of the Day (SOD) and Surface Airways (SA) stations. Information from these stations were also used for the meteorological inputs for the WASP water quality model and consisted of air temperature, solar radiation, fraction of day light based on the cloud cover and wind speed.

It is important to note that cloud cover is a difficult parameter to characterize in modeling applications. As cloud cover, or sky condition, is typically reported from an observer, not monitoring equipment, there are inherent challenges in its development. For consistency, it is preferred that cloud cover come from the same station for the entire simulation period. Therefore, all the meteorological inputs were obtained from the NCDC station Crestwood 4 NE in Oldham County, KY (151900) and were applied to the entire model.

Figure 4-5 shows spatial extent of the meteorological stations used in the LSPC watershed model and the WASP water quality model. Figures 4-6 and 4-7 show the meteorological data input of solar radiation and wind speed, respectively, into the WASP model.

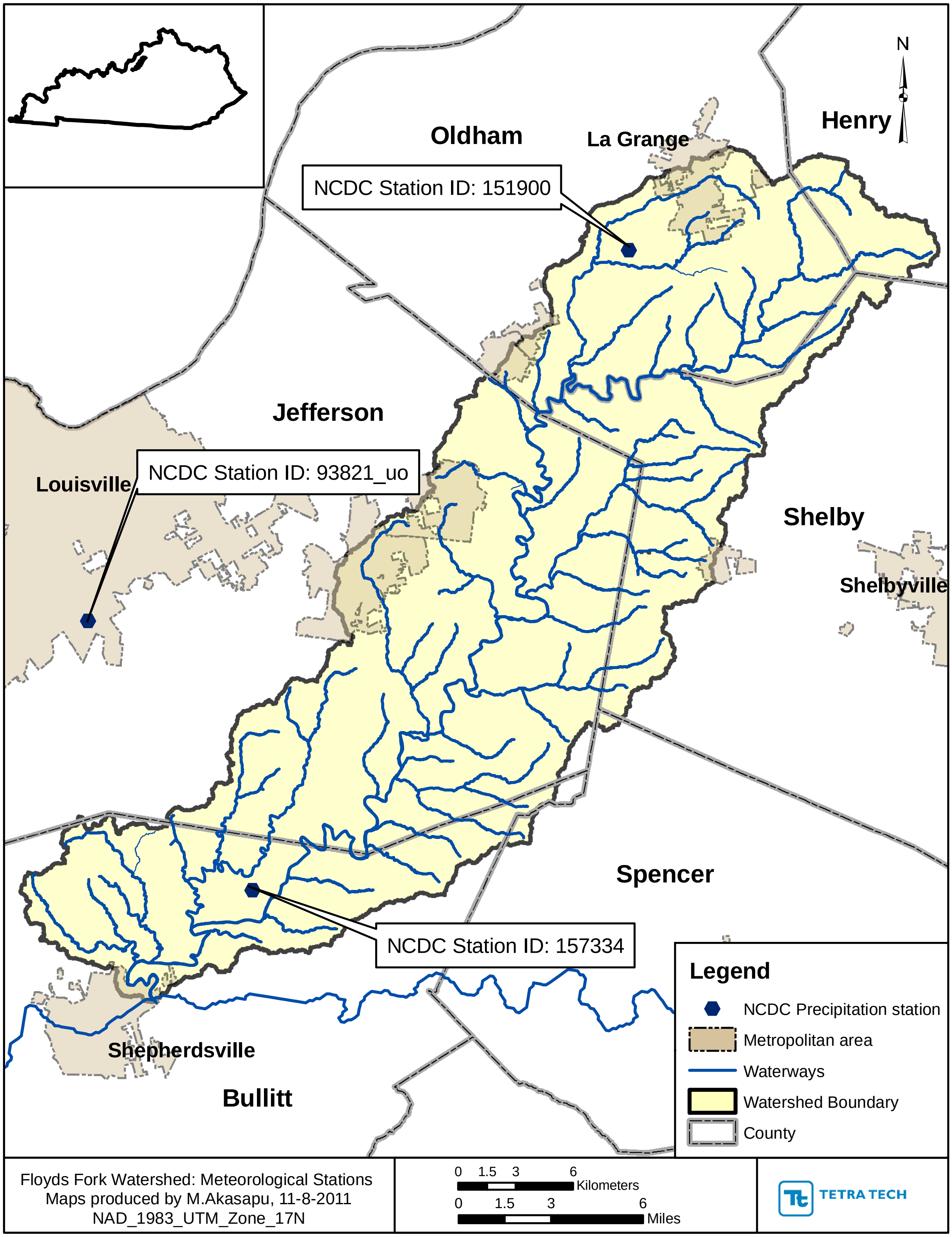

Figure 4-5 Location of the Meteorological Stations used in the WASP Water Quality model

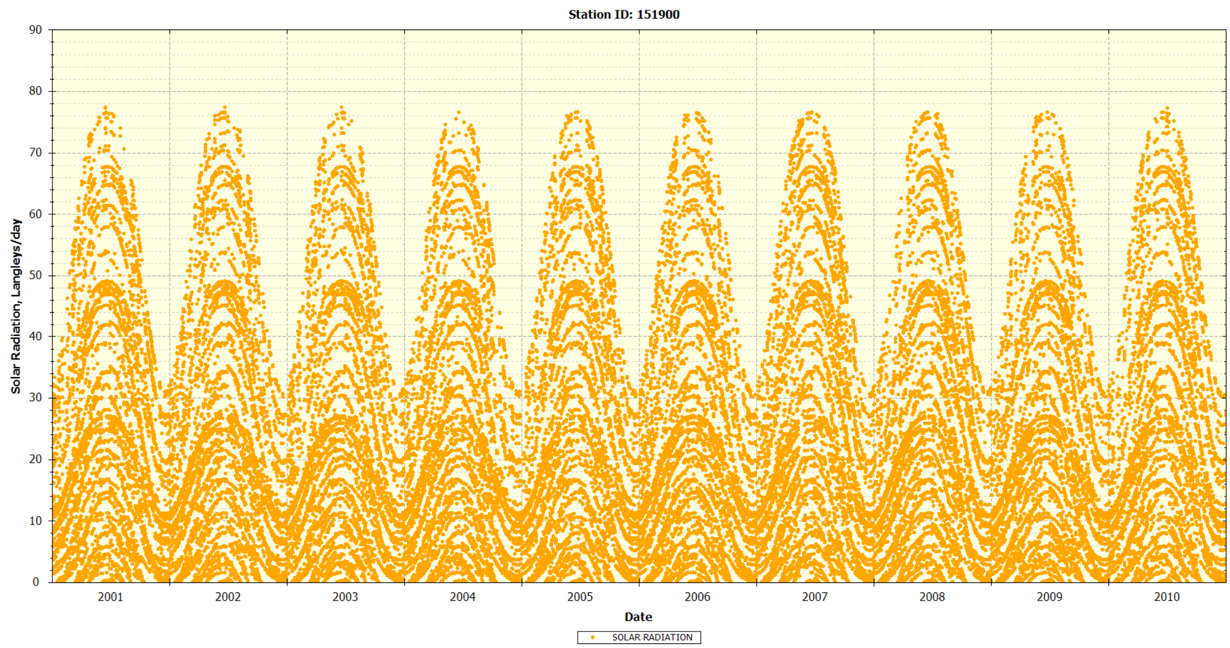

Figure 4-6 Meteorological input of Solar Radiation into the WASP Water Quality model

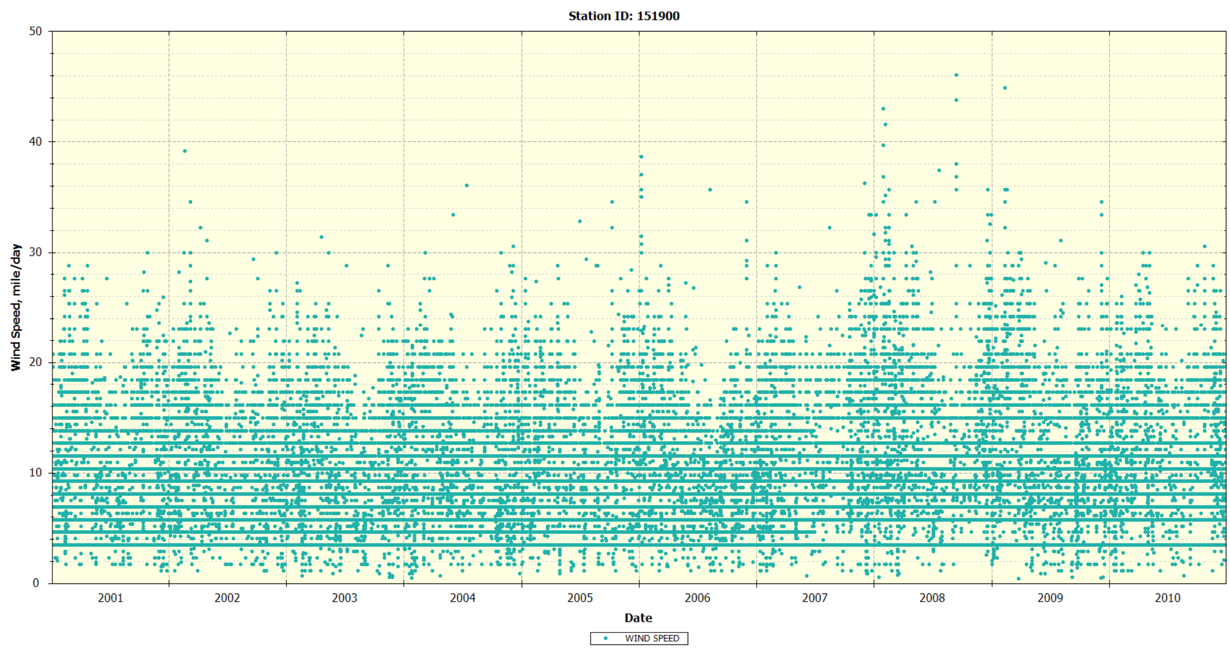

Figure 4-7 Meteorological input of Wind Speed into the WASP Water Quality model

4.5 Flow and Water Quality Boundary Conditions

4.5.1 Watershed Inputs

As mentioned in Section 2.2, inputs for the watershed flows and water quality concentrations were obtained from the LSPC watershed model. Two parameters were used to characterize the inflows from the LSPC model, the subwatershed overland flows (PEROs) and the in-stream flows (ROs). In the LSPC model, PEROs are designated by the sum of surface, interflow and groundwater outflow volume for an individual subwatershed whereas ROs are designated by the total rate of outflow from all the reaches contributing to the downstream subwatershed.

Table 4-1 shows the WASP segments associated with in-stream (RO) and overland (PERO) flow, along with the corresponding WASP flow function name and LSPC watershed.

Table 4-1 Flow Paths of the WASP Segments utilizing ROs and PEROs in the Floyds Fork model

RO Flows			PERO Flows		
Flow Function	WASP Segment	LSPC Watershed	Flow Function	WASP Segment	LSPC Watershed
East Fork Floyds Fork	42	246	PERO_103_102_101*	1	103_102_101
North Fork Floyds Fork	45	245	PERO_110	2	110
Gathright Branch	47	243	PERO_120	3	120
FlowPath 22	50	240	PERO_123	4	123
FlowPath 23	52	240	PERO_138	5	138
Lick Fork	56	239	PERO_140_142_143_144*	6	140_142_143_144
FlowPath 18	60	236	PERO_149	8	149
Junkins Run	63	235	PERO_145_148*	7	145_148
FlowPath 17	64	231	PERO_152	9	152
North Fork Currys Fork	70	210	PERO_153	10	153
South Fork Currys Fork	75	219	PERO_155_157*	11	155_157
Ashers Run	78	208	PERO_159	12	159
FlowPath 27	80	202	PERO_170	14	170
FlowPath 28	82	197	PERO_172	17	172
FlowPath 29	84	195	PERO_175	19	175
Chenoweth Run	86	188	PERO_181_183*	20	181_183
FlowPath 30	88	188	PERO_185	23	185
Brush Run	90	187	PERO_186	24	186
FlowPath 8	98	265	PERO_189	26	189
Lang Run	100	266	PERO_194	27	194
Tater Run	102	264	PERO_200_198*	28	200_198
FlowPath 12	106	272	PERO_203_201*	29	203_201
Dalton Run	107	273	PERO_228_205*	30	228_205
South Long Run	112	277	PERO_229	31	229
FlowPath 6	113	276	PERO_230	32	230
Shakes Run	115	257	PERO_232_233*	33	232_233
Brush Run	117	182	PERO_234	34	234
Pope Lick	120	178	PERO_237	36	237
FlowPath 35	121	176	PERO_238	37	238
FlowPath 36	122	175	PERO_241	38	241
Cane Run	128	284	PERO_242	39	242
Sheckels Run	130	285	PERO_244	40	244
FlowPath 39	133	171	FlowPath 25	58	237
Brush Run	134	171	PERO_206_204*	65	206_204
Chenoweth Run	141	167	PERO_207	66	207
Razor Branch	144	163	PERO_209	67	209
Shinks Branch	147	161	PERO_211	71	211
Turkey Run	149	156	PERO_215_216*	73	215_216
Back Run	153	293	PERO_196_193*	83	196_193
Wheelers Run	154	294	PERO_184	91	184
Broad Run	157	292	PERO_256	92	256
Big Run	159	151	PERO_258	93	258
Old Mans Run	161	150	PERO_259	94	259
FlowPath 45	164	146	PERO_261	95	261
Wells Run	166	141	PERO_263	96	263
Bethel Branch	168	139	PERO_262_271*	104	262_271
Cedar Creek	176	137	PERO_260_274_275*	110	260_274_275
Little Cedar Creek	178	136	PERO_174	118	174
FlowPath 48	184	131	PERO_177	119	177
FlowPath 49	186	132	PERO_173	123	173
Tanyard Branch	188	124	PERO_283	125	283
FlowPath 53	189	121	PERO_158	135	158
Brooks Run	192	116	PERO_160	136	160
FlowPath 55	196	112	PERO_162	137	162
Bluelick Creek	200	106	PERO_164_166*	139	164_166
FlowPath 57	202	106	PERO_154	150	154
Clear Run	204	107	PERO_291	151	291
UT To Brook Run	205	118	PERO_122	169	122
UT to South Fork Curry	206	218	PERO_126	170	126
PERO_217	207	217	PERO_128	171	128
			PERO_133	172	133
			PERO_134	173	134
			PERO_135	174	135
			PERO_127	179	127
			PERO_129	180	129
			PERO_130	181	130
			PERO_109	190	109
			PERO_115_114_113*	191	115_114_113
			PERO_104	197	104
			PERO_180	209	180
			PERO_169	212	169

* Combination of Inputs from the respective LSPC subwatersheds

4.5.2 Point Sources

There are 73 NPDES point source discharges located in the Floyds Fork watershed, of which, 6 are Municipal, 20 are Subdivisions, 4 are Schools and 43 are Small Sewage (including general residences) facilities (Figure 4-8). Flows and effluent monitoring data for these point source discharges were obtained from both the Kentucky Division of Water (KDOW) and the Environmental Protection Agency's (EPA) Permit Compliance System (PCS) in the form of Discharge Monitoring Reports (DMR). Data obtained from these reports were input directly into the WASP water quality model as daily load time-series from 2001 through 2010. This was achieved by holding the monthly averages constant for the entire month. However, for the few facilities with daily effluent data, the loads were input into the model as reported in the DMR's.

Many of the permitted dischargers did not report loads or concentrations for one or more constituents. Therefore, default concentrations were assumed. This was especially true for temperature as none of the facilities are required by their permit to report effluent temperatures.

In addition to the NPDES point sources, non-failing septic systems were also input in the WASP model. This was done for 202 of the watersheds. A more detailed discussion of how the time-series were developed for each of the NPDES point sources and non-failing septic systems is presented in "Watershed Hydrology and Water Quality Modeling Report for Floyds Fork, Kentucky – REV 4" (Tetra Tech 2012).

4.5.3 Sanitary Sewer Overflows

Data on CSO's/SSO's for the Floyds Fork watershed were obtained from the Kentucky Pollutant Discharge Elimination system's (KPDES) DMR and incident and facility reports on SSO's. SSO's from 33 NPDES facilities were reported for their respective WQTC permit from these two sources (Table 4-2). Ten out of the 33 facilities had data from both the DMR and the incident and facility reports, whereas six facilities had no quantifiable data and therefore only 27 SSO's were input into the model (Figure 4-8). Table 4-2 shows the number of events quantified for the NPDES facilities from each source. Only data from incident and facility reports were input into the model. However, the 10 facilities with data from two sources (Incident/facility reports and DMR data) shared common overflow data and some multiple overflows reported on the same day between them. Therefore, the total number of events input into the model for these 10 common facilities (Table 4-3) was not the sum of the events quantified from the two sources mentioned in Table 4-2. The data was further validated by the Water Quality Treatment Center (WQTC) reports posted on MSD's Project WIN website (www.msdlouky.org/projectwin/). According to the CSO's/SSO's overflow locations published on Project WIN, there were no CSO's in the Floyds Fork watershed.

The reported discharge amount for the SSO's was utilized to develop flow and load time-series inputs on a daily scale. Flows and loads for the SSO's were only developed for the days with data (i.e., only when overflows or bypasses occurred). It was assumed that for all other days, there were no SSO's, so the flow and loads were zero. A more detailed discussion of how the time-series were developed for each of the SSO's is presented in "Watershed Hydrology and Water Quality Modeling Report for Floyds Fork, Kentucky – REV 4" (Tetra Tech 2012).

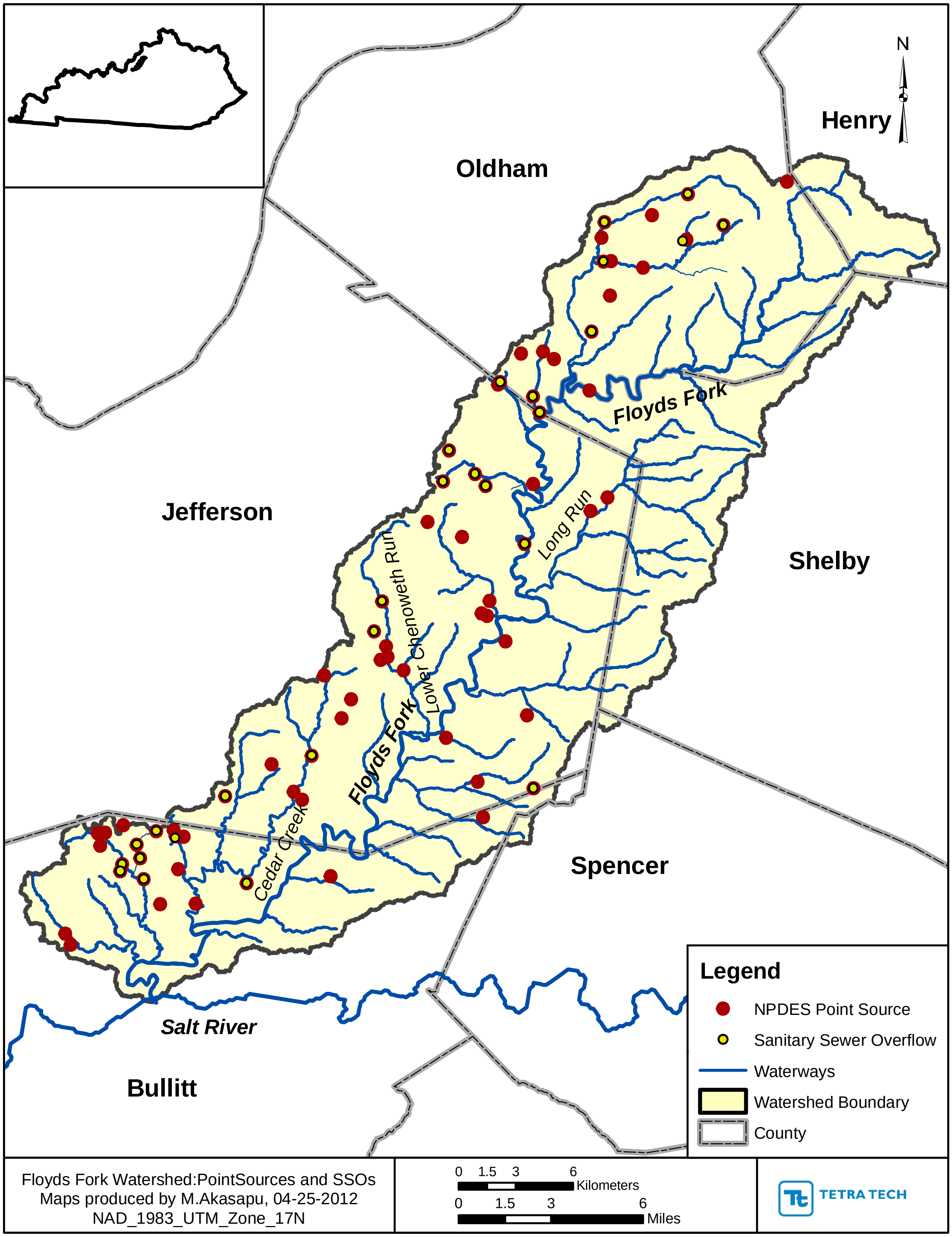

Figure 4-8 NPDES Point Sources and SSO's Locations

Table 4-2 Data on Sanitary Sewer Overflows (SSO's)

Source: Incident and Facility reports			
NPDES Point Source	No. of events recorded	No. of events quantified	Range of Dates
KY0020001	93	26	12/18/2002-11/26/2010
KY0023078	1	0	6/1/2003
KY0024724	87	19	1/2/2003-10/2/2009
KY0025194	140	70	7/9/2003-12/10/2010
KY0029416	4	4	5/2/2008-7/22/2010
KY0029441	17	8	2/21/2003-9/9/2009
KY0029459	21	19	3/31/2004-12/8/2010
KY0031712	10	6	9/8/2003-5/2/2010
KY0034151	9	2	8/20/2003-12/12/2010
KY0034169	10	2	1/25/2005-9/14/2008
KY0034177	7	2	5/26/2006-9/14/2008
KY0034185	24	6	5/9/2005-10/9/2009
KY0034801	15	0	2/23/2003-6/23/2008
KY0036501	9	5	1/2/2003-5/2/2010
KY0038610	90	51	4/18/2003-11/30/2010
KY0039004	4	2	9/14/2008-2/19/2010
KY0039870	7	5	11/12/2003-7/29/2009
KY0042153	3	0	5/23/2003-9/20/2007
KY0042226	13	13	6/13/2003-10/12/2010
KY0044342	1	0	8/24/2007
KY0054674	14	7	1/16/2004-9/27/2009
KY0060577	20	7	2/21/2003-7/9/2009
KY0069485	5	2	5/23/2007-7/10/2008
KY0077674	8	5	1/1/2003-5/6/2010
KY0086843	6	2	7/28/2003-7/21/2010
KY0090956	4	0	3/4/2008-11/29/2010
KY0094307	3	1	2/1/2003-9/14/2008
KY0098540	64	49	1/2/2003-11/16/2010
KY0100994	4	0	1/10/2003
KY0101419	12	6	5/20/2003-11/26/2010
KY0102784	26	18	5/5/2003-11/19/2010
KY0103110	96	91	8/25/2003-10/28/2009
KY0103900	25	2	9/2/2003-9/19/2010
Source: DMR			
NPDES Point Source	No. of events recorded	No. of events quantified	Range of Dates
KY0025194	-	155	1/2/2005-12/10/2010
KY0029416	-	4	5/3/2008-7/22/2010
KY0029459	-	17	4/4/2008-12/8/2010
KY0031712	-	5	1/24/2008-5/2/2010
KY0036501	-	5	3/13/2006-5/2/2010
KY0039004	-	0	-
KY0042226	-	20	1/1/2005-10/12/2010
KY0044342	-	0	-
KY0098540	-	47	1/4/2005-11/16/2010
KY0102784	-	16	3/9/2005-11/19/2010

Table 4-3 Common Data on Sanitary Sewer Overflows (SSO's)

NPDES Point Source	Total no. of events recorded from the two sources	No. of events input into the model	Range of Dates
KY0025194	295	85	7/9/2003-12/10/2010
KY0029416	8	4	5/2/2008-7/22/2010
KY0029459	38	17	3/31/2004-12/8/2010
KY0031712	15	5	9/8/2003-5/2/2010
KY0036501	14	6	1/2/2003-5/2/2010
KY0042226	33	18	6/13/2003-10/12/2010
KY0098540	111	42	1/2/2003-11/16/2010
KY0102784	42	19	5/5/2003-11/19/2010

4.5.4 Water Withdrawals

There are 11 industrial water withdrawals located in the Floyds Fork watershed (Table 4-4). Monthly average water withdrawal data were obtained from KDOW. Data obtained from KDOW were input directly into the WASP water quality model from 2001 through 2010. For security reasons, the location of the Water withdrawals cannot be disclosed.

Table 4-4 Summary of Industrial Withdrawal in the Floyds Fork Watershed

Withdrawal Name	Permit Number	Source Water	Sub-Watershed	Monthly Permitted Withdrawal	
				Month	Limit (MGD)
KY Solite Corp	0987	Large reservoir south of Brooks Run	107	October - March	0.202
				April - September	0.310
Persimmon Ridge Subdivision	1020	Irrigation lake#1	228	October - April	0.000
				May - September	0.300
Persimmon Ridge Subdivision	1090	Irrigation lake#1	228	November - February	0.000
				March - October	0.300
Quail Chase Golf Club	1093	McNeely lake, an impoundment of Pennsylvania Run	131	December - March	0.000
				April and November	1.000
				May - October	1.250
Polo Fileds Golf Course	1257	Polo fields Lake, an impoundment of Brush Run	187	November - March	0.000
				April and October	0.250
				May - September	0.500
Polo Fileds Golf Course	1258	Polo fields Lake, an impoundment of Brush Run	187	November - March	0.000
				April and October	0.250
				May - September	0.500
Action Landscape, Inc.	1264	RM 4.3 OF Chenoweth Run	167	March - May and September	0.010
				June	0.018
				July - August	0.024
Midland Trail Golf Club	1315	RM 37.55 of Floyds Fork	185	December - February	0.000
				March and November	0.250
				April - May and October	0.500
				June and Spetember	0.800
Rogers Group, Inc.- Bullitt Co Stone	1353	Bullitt County Stone quarry pit	109	January - December	1.100
Rogers Group, Inc.- Jefferson Co Stone	1355	Jefferson County Stone quarry	192	January - December	0.350
The Cardinal Club, LLC	1460	RM 5.2 of South Long Run (impoundment), a tributary of Long Run	278	October - April	0.000
				May - September	0.100

4.5.5 Springs

The USGS has identified 20 springs in the Floyds Fork watershed which are concentrated along the main stem of Floyds Fork (Figure 4-9). A list of the 20 springs with their respective discharges used in the model is tabulated in Table 4-5. The water quality concentrations used for the springs were average groundwater concentrations taken from KGS's groundwater-quality database of the Kentucky groundwater data repository (Table 3-12). The flow and groundwater concentration for the springs were input directly into the WASP model as time-series from 2001 to 2010.

Table 4-5 Springs in the Floyds Fork Watershed

Spring Number	USGS Name	County	Discharge, cfs
SPR1	E17CS001	Bullitt	0.10
SPR2	E17BS002	Jefferson	0.10
SPR3	E17BS004	Jefferson	0.10
SPR4	E17BS001	Jefferson	0.10
SPR5	E18AS002	Jefferson	0.10
SPR6	E18AS001	Jefferson	0.10
SPR7	E17BS003	Jefferson	1.30
SPR8	E17BS006	Jefferson	0.10
SPR9	E17BS005	Jefferson	0.10
SPR10	D18C009	Jefferson	0.05
SPR11	D18CS004	Jefferson	0.05
SPR12	D18CS006	Jefferson	0.05
SPR13	D18C005	Jefferson	0.05
SPR14	D18CS007	Jefferson	0.10
SPR15	D18CS008	Jefferson	0.10
SPR16	D18CS011	Shelby	0.05
SPR17	D18BS002	Oldham	0.05
SPR18	D18BS003	Oldham	0.05
SPR19	D18BS004	Oldham	0.10
SPR20	ANITA SPRGS. WATER CO. - 1185001	Oldham	0.10

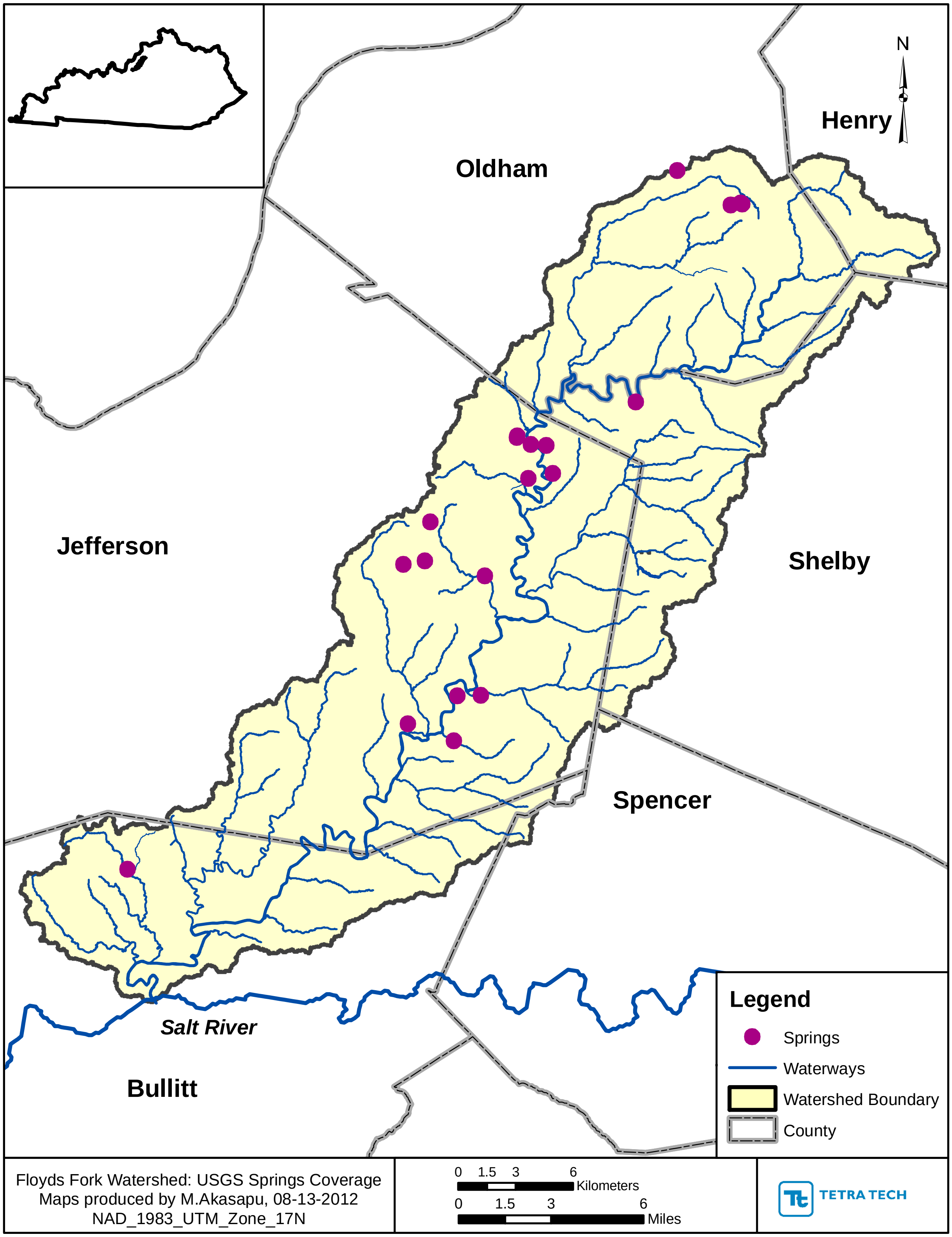

Figure 4-9 Springs in the Floyds Fork Watershed

4.5.6 Aggregation of WASP Inputs

Based on the location of the NPDES point sources, SSO’s, water withdrawals, non-failing septics, and springs with respect to the WASP segments, flows from these sources were aggregated with the landuse flows. These flows were then input into the WASP water quality model at their respective flow boundaries. The loads of all the point sources and SSO’s discharging into the same WASP segment were also aggregated prior to inputting into the WASP model. For the aggregation of landuse based concentrations of the water quality constituents, the location of the LSPC subwatersheds, and the type of flow (overland and in-stream) associated with the WASP segment was considered. Additionally, the loads from point sources and SSO’s, and the landuse based concentrations of the water quality constituents were supplied to the WASP model at separate locations in the model, as mass and concentration respectively. The process of aggregating the different source inputs to provide only one input to the model per segment was done to simplify the process of settling up the water quality model. This process not only helped reduce the pre-processing time but also decreased the runtime of the WASP model.

The flows, loads and concentrations of all the water quality constituents were linked to the WASP water quality model by Database (*.DB) files. A total of 9 DB files were used, one DB file was used for all flows containing the aggregated overland flows and the in-stream flows, three DB files were used for the loads from point sources and SSO’s for TN, TP and the remaining water quality constituents, and five DB files were used for TN, TP, DO, BOD and SEDIMENTS respectively for the landuse based concentrations.

Table 4-6 shows the WASP segments with the inputs from point sources, SSO’s, water withdrawals, non-failing septics, and springs. Figures 4-10 through 4-12 shows the locations of the point source, SSO’s, water withdrawals, and springs into each WASP segment for the top, middle and bottom portion of the watershed respectively.

Table 4-6 WASP Segments associated with Point Sources, SSO's, Water Withdrawals, Non-failing Septics, and Springs

WASP	LSPC SWS	Point Sources, SSOs, WDs, and Springs associated with the WASP segment	WASP	LSPC SWS	Point Sources, SSOs, WDs, and Springs associated with the WASP segment
1	101_102_103, 105	nonfail_septic_101*, nonfail_septic_102*, nonfail_septic_103*, nonfail_septic_105*	47	243	nonfail_septic_243*, nonfail_septic_251*, nonfail_septic_252*
2	110	nonfail_septic_110*	50	240	nonfail_septic_240*
3	120	nonfail_septic_120*	56	239	nonfail_septic_239*, nonfail_septic_253*, nonfail_septic_254*
4	123	nonfail_septic_123*	58	237	nonfail_septic_237*
5	138	nonfail_septic_138*	60	236	nonfail_septic_236*
6	140_142_143_144	nonfail_septic_140*, nonfail_septic_142*, nonfail_septic_143*, nonfail_septic_144*	63	235	nonfail_septic_235*
7	145_148	nonfail_septic_145*, nonfail_septic_148*	64	231	nonfail_septic_231*
8	149	nonfail_septic_149*	65	204_206	nonfail_septic_204*, nonfail_septic_206*
9	152	nonfail_septic_152*	66	207	KY0060577, KYG400147, KY0060577_SSO#, nonfail_septic_207*
10	153	nonfail_septic_153*	67	209	nonfail_septic_209*
11	155_157	nonfail_septic_155*, nonfail_septic_157*	70	210	KY0020001, KYG400112, KY0103110, KYG400105, KY0103110_SSO#, KY0020001_SSO#, nonfail_septic_210*, nonfail_septic_212*, nonfail_septic_213*, nonfail_septic_214*, SPR17^, SPR18^, SPR19^, SPR20^
12	159	nonfail_septic_159*	71	211	KY0076732, KYG400289, KY0054674, KY0054674_SSO#, nonfail_septic_211*
14	170	nonfail_septic_170*, SPR4^	73	215_216	nonfail_septic_215*, nonfail_septic_216*
17	172	KY0042153, nonfail_septic_172*	75	219	KY0029441, KY0029441_SSO#, nonfail_septic_219*, nonfail_septic_221*, nonfail_septic_222*, nonfail_septic_223*
20	181_183	nonfail_septic_181*, nonfail_septic_183*	78	208	nonfail_septic_208*, nonfail_septic_224*, nonfail_septic_225*, nonfail_septic_226*, nonfail_septic_227*
23	185	KY0102784, KY0102784_SSO#, nonfail_septic_185*, 1315**	80	202	nonfail_septic_202*, nonfail_septic_255*
26	189	KYG400613, nonfail_septic_189*, SPR11^, SPR12^, SPR13^	82	197	KY0076741, KYG400082, KY0024724, KY0024724_SSO#, nonfail_septic_197*, nonfail_septic_199*
27	194	nonfail_septic_194*	83	193_196	nonfail_septic_193*, nonfail_septic_196*, SPR14^, SPR15^
28	198_200	KY0039004, KY0039004_SSO#, nonfail_septic_198*, nonfail_septic_200*	84	195	KY0069485, KYG400235, KY0069485_SSO#, nonfail_septic_195*
29	201_203	KY0105384, nonfail_septic_201*, nonfail_septic_203*	86	188	KY0036501, KY0031712, KY0086843, KY0042226, KY0036501_SSO#, KY0042226_SSO#, KY0031712_SSO#, KY0086843_SSO#. nonfail_septic_188*, nonfail_septic_190*, nonfail_septic_191*, nonfail_septic_192*, 1355**, SPR10
30	205_228	KY0090956, nonfail_septic_205*, nonfail_septic_228*, 1020**, 1090**	90	187	nonfail_septic_187*, 1257**, 1258**
31	229	nonfail_septic_229*	91	184	nonfail_septic_184*
32	230	nonfail_septic_230*, SPR16^	92	256	nonfail_septic_256*
33	232_233	nonfail_septic_232*, nonfail_septic_233*	93	258	nonfail_septic_258*
34	234	nonfail_septic_234*	94	259	KYG400250, KYG400128, nonfail_septic_259*
37	238	nonfail_septic_238*	95	261	nonfail_septic_261*
38	241	nonfail_septic_241*	96	263	nonfail_septic_263*
39	242	nonfail_septic_242*	98	265	nonfail_septic_265*, nonfail_septic_267*, nonfail_septic_268*
40	244	nonfail_septic_244*	100	266	nonfail_septic_266*, nonfail_septic_269*
42	246	nonfail_septic_246*, nonfail_septic_249*, nonfail_septic_250*	102	264	nonfail_septic_264*, nonfail_septic_270*
45	245	KY0031798, nonfail_septic_245*, nonfail_septic_247*, nonfail_septic_248*	104	262_271	nonfail_septic_262*, nonfail_septic_271*

* : nonfail_septic_XXX represents the non failing septics in the model.

**: XXXX represents the Water Withdrawals in the model.

#: KYXXXXXX_SSO represents the reported overflow/bypass at the KYXXXXXX facility.

^ : SPR_XXX represents the springs in the model.

Table 4-6 WASP Segments associated with Point Sources, SSO's, Water Withdrawals, Non-failing Septics, and Springs (cont.)

WASP	LSPC SWS	Point Sources, SSOs, WDs, and Springs associated with the WASP segment	WASP	LSPC SWS	Point Sources, SSOs, WDs, and Springs associated with the WASP segment
106	272	nonfail_septic_272*	161	150	nonfail_septic_150*, nonfail_septic_301*, nonfail_septic_302*
107	273	nonfail_septic_273*	164	146	nonfail_septic_146*, nonfail_septic_147*
110	260_274_275	nonfail_septic_260*, nonfail_septic_274*, nonfail_septic_275*	166	141	KYG401875, nonfail_septic_141*
112	277	nonfail_septic_277*, nonfail_septic_278*, 1460**	168	139	nonfail_septic_139*
113	276	nonfail_septic_276*	169	122	nonfail_septic_122*
115	257	nonfail_septic_257*, nonfail_septic_279*, nonfail_septic_280*	170	126	nonfail_septic_126*
117	182	nonfail_septic_182*, nonfail_septic_281*, nonfail_septic_282*	171	128	KY0077674, KY0077674_SSO#, nonfail_septic_128*
118	174	KYG402142, KYG400153, KYG400259, nonfail_septic_174*, SPR6^	172	133	nonfail_septic_133*
119	177	nonfail_septic_177*, SPR8	173	134	KYG400166, KYG400139, nonfail_septic_134*
120	178	KYG400028, KYG400194, nonfail_septic_178*, nonfail_septic_179*, SPR9^	174	135	KY0098540, KY0098540_SSO#, nonfail_septic_135*
121	176	nonfail_septic_176*	176	137	KYG400032, KYG400177, nonfail_septic_137*
122	175	KY0073059, nonfail_septic_175*	178	136	nonfail_septic_136*
123	173	nonfail_septic_173*, SPR5^	179	127	nonfail_septic_127*
125	283	nonfail_septic_283*	180	129	nonfail_septic_129*
128	284	nonfail_septic_284*, nonfail_septic_290*, nonfail_septic_289*, nonfail_septic_288*, nonfail_septic_287*, nonfail_septic_286*	181	130	KY0029416, KY0029416_SSO#, nonfail_septic_130*
130	285	KYG400403, nonfail_septic_285*	184	131	nonfail_septic_131*, 1093**, SPR21^
134	171	KYG400189, nonfail_septic_171*, SPR2^	186	132	KYG400137, nonfail_septic_132*
135	158	nonfail_septic_158*, SPR3	188	124	KY0040193, KY0034801, KY0034151, KY0101885, KY0034151_SSO#, nonfail_septic_124*, nonfail_septic_125*
136	160	nonfail_septic_160*	189	121	nonfail_septic_121*
137	162	KY0029459, KYG400251, KY0044432, KYG400150, KY0029459_SSO#, nonfail_septic_162*	190	109,111	nonfail_septic_109*, nonfail_septic_111*, 1353**
139	164_166	KY0025194, KY0025194_SSO#, nonfail_septic_165*, nonfail_septic_164*, nonfail_septic_166*	191	113_114_115	KY0100994, KY0034185, KY0034185_SSO#, nonfail_septic_113*, nonfail_septic_114*, nonfail_septic_115*
141	167	nonfail_septic_167*, nonfail_septic_168*, 1264**, SPR7^	192	116	KY0023078, KY0077666, KY0102873, KYG400329, KY0094307, KY0103900, KY0094307_SSO#, KY0103900_SSO#, nonfail_septic_116*, nonfail_septic_117*, SPR192^
144	163	KYG400161, nonfail_septic_163*	196	112	nonfail_septic_112*
147	161	nonfail_septic_161*	197	104	nonfail_septic_104*
149	156	nonfail_septic_156*	200	106	KY0072168, KYG400420, nonfail_septic_106*, nonfail_septic_108*
150	154	nonfail_septic_154*	204	107	nonfail_septic_107*, 0987**
151	291	nonfail_septic_291*	205	118	KY0034169, KY0038610, KY0034177, KY0034169_SSO#, KY0034177_SSO#, KY0038610_SSO#, nonfail_septic_118*, nonfail_septic_119*
153	293	KY0101419, KYG400010, KY0101419_SSO#, nonfail_septic_293*	206	218	KY0039870, KY0039870_SSO#, nonfail_septic_218*, nonfail_septic_220*
154	294	nonfail_septic_294*, nonfail_septic_295*, nonfail_septic_296*	207	217	nonfail_septic_217*
157	292	KYG401905, nonfail_septic_292*, nonfail_septic_297*, nonfail_septic_298*, nonfail_septic_299*, nonfail_septic_300*	209	180	nonfail_septic_180*
159	151	KY0026972, nonfail_septic_151*	212	169	nonfail_septic_169*

* : nonfail_septic_XXX represents the non failing septics in the model.

**: XXXX represents the Water Withdrawals in the model.

#: KYXXXXXX_SSO represents the reported overflow/bypass at the KYXXXXXX facility.

^ : SPR_XXX represents the springs in the model.

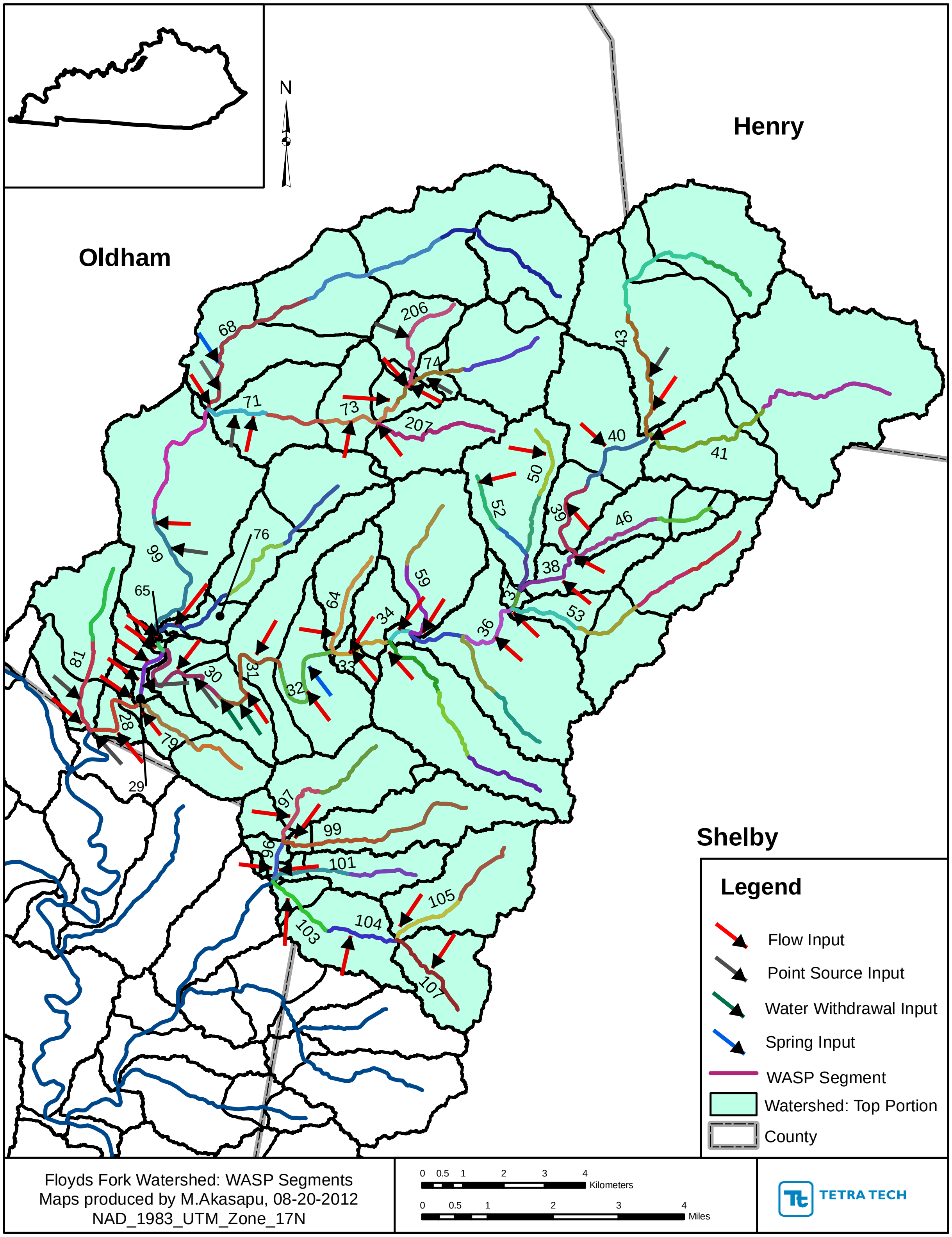

Figure 4-10 Point Sources, SSO's, Water Withdrawals, and Springs Input into Model, Top portion of the Wateshed

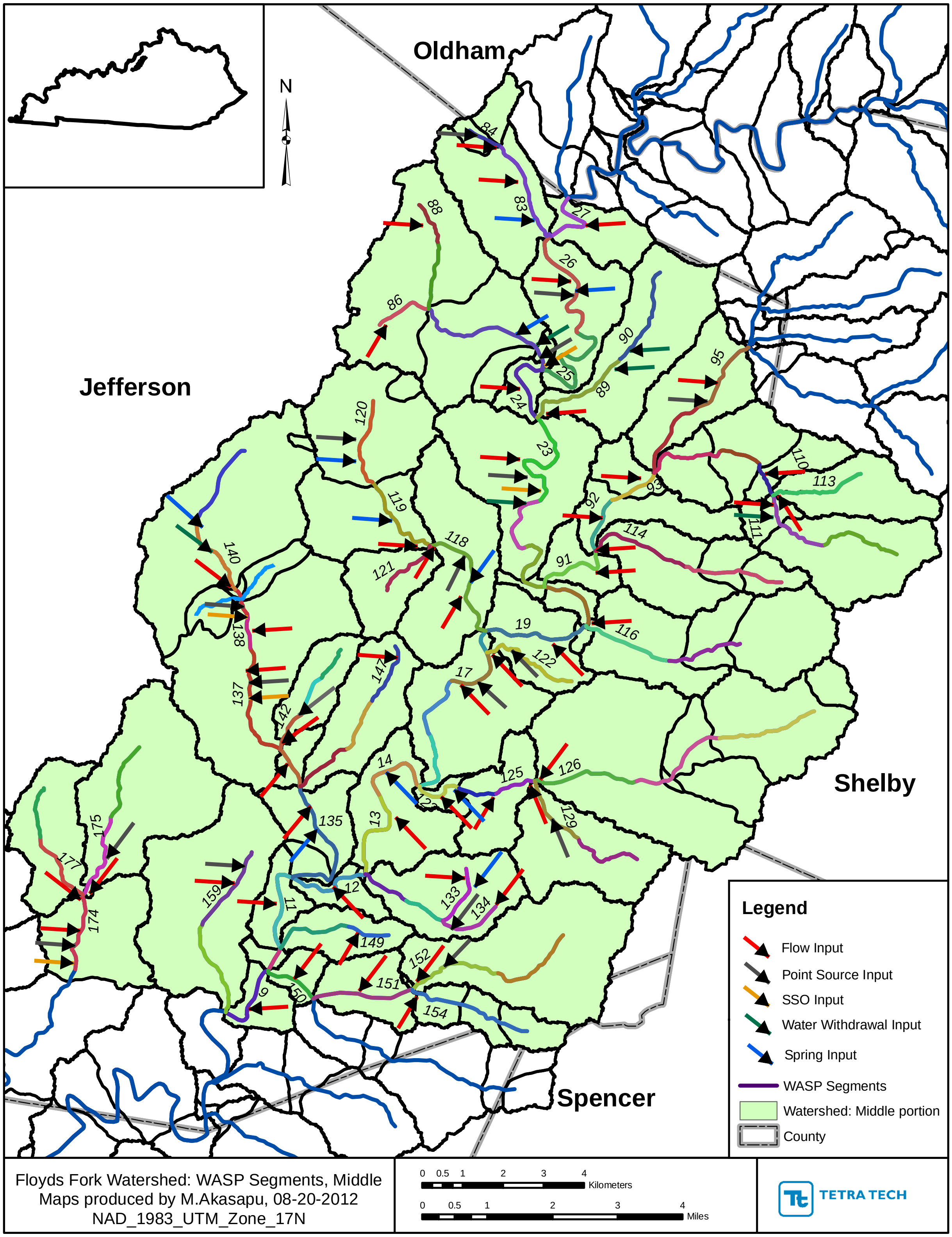

Figure 4-11 Point Sources, SSO's, Water Withdrawals, and Springs Input into Model, Middle portion of the Watershed

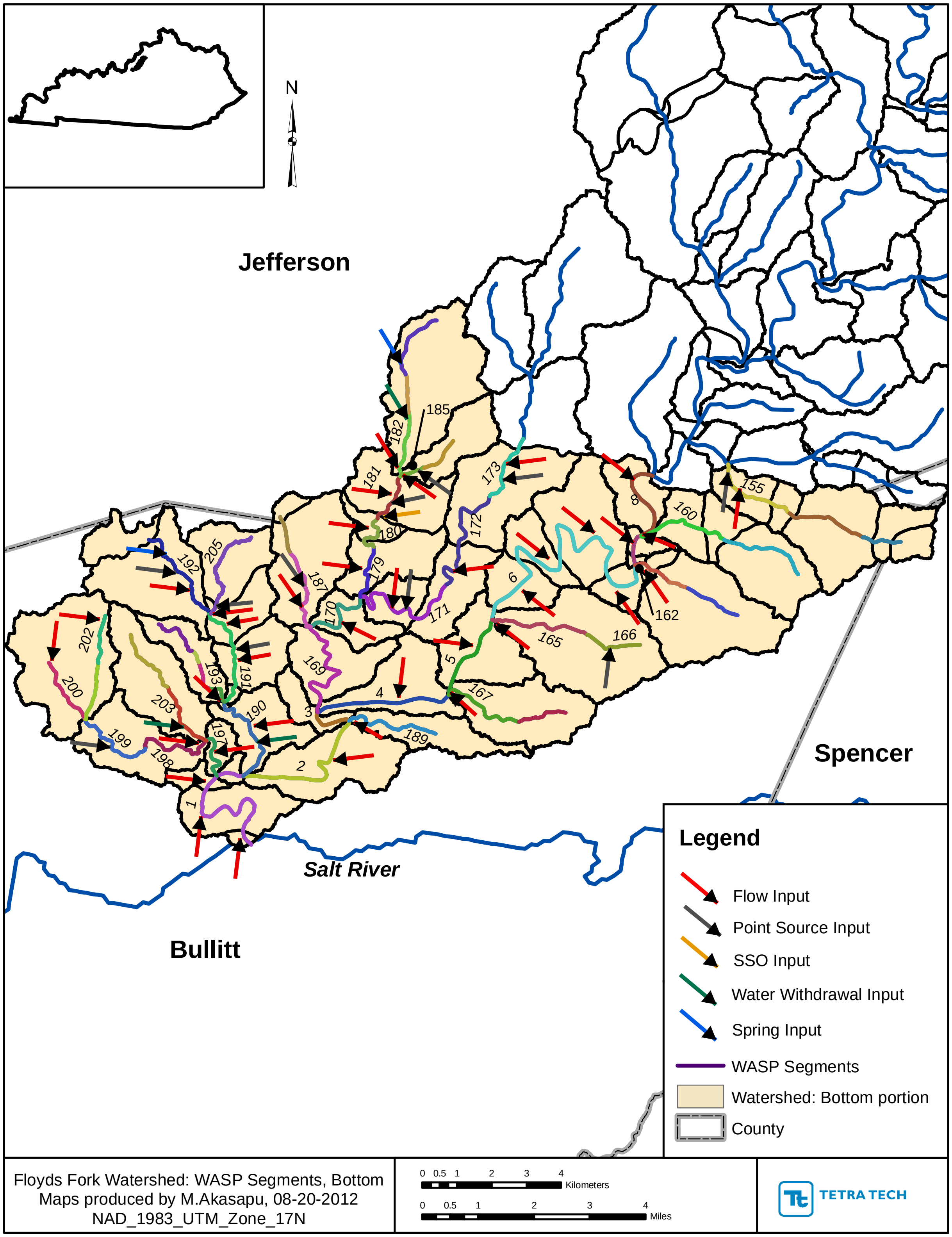

Figure 4-12 Point Sources, SSO's, Water Withdrawals, and Springs Input into Model, Bottom Portion of the Watershed

4.6 Sediment Oxygen Demand

A large fraction of oxygen consumption in surface waters comes from benthic sediments and organisms. Significant effects can be observed in the concentrations of oxygen from the decomposition of organic material. No observed sediment oxygen demand flux was available to be specified for the water segments. Therefore, values of sediment oxygen demand varying from 0 g O_2/m^2/day to 8 g O_2/m^2/day were used during the calibration.

4.7 Nutrient Fluxes

There was no measured data on nutrient fluxes. In the current model, neither benthic ammonia nor benthic phosphorus flux were utilized.

4.8 Rates and Constants

The rates and constants that were used in the WASP water quality model are presented in Tables 4-7 through 4-12.

Table 4-7 Constants used for Inorganic Nutrients

Constants	Used	Value
Nitrification Rate Constant @ 20°C (1/day)	Yes	0.2
Nitrification Temperature Coefficient	Yes	1.07
Half Saturation Constant for Nitrification Oxygen Limit (mg O2/L)	Yes	0.5
Minimum Temperature for Nitrification Reaction (°C)	No	0.0
Denitrification Rate Constant @ 20°C (1/day)	Yes	0.05
Denitrification Temperature Coefficient	Yes	1.07
Half Saturation Constant for Denitrification Oxygen Limit (mg O2/L)	Yes	0.1

Table 4-8 Constants used for Organic Nutrients

Constants	Used	Value
Detritus Dissolution Rate (1/day)	Yes	0.01
Temperature Correction for detritus dissolution	Yes	1.04
Dissolved Organic Nitrogen Mineralization Rate Constant @ 20°C (1/day)	Yes	0.05
Dissolved Organic Nitrogen Mineralization Temperature Coefficient	Yes	1.04
Dissolved Organic Phosphorus Mineralization Rate Constant @ 20°C (1/day)	Yes	0.03
Dissolved Organic Phosphorus Mineralization Temperature Coefficient	Yes	1.08
Phytoplankton Half Saturation for Mineralization Rate (mg Phyt C/L)	No	0.0

Table 4-9 Constants used for Benthic Algae

Constants	Used	Value
Benthic Algae D:C Ratio (mg D/ mg C)	No	0.0
Benthic Algae N : C Ratio (mg N/mg C)	Yes	0.1
Benthic Algae P : Carbon Ratio (mg P/mg C)	Yes	0.01
Benthic Algae Chl a : C Ratio (mg Chl/mg C)	Yes	0.025
Benthic Algae O2 : C Production (mg O2/ mg C)	Yes	1
Growth Model, 0= Zero Order; 1= First Order	Yes	0
Max.Growth Rate (gD/m2-day, or 1/day)	Yes	3
Temp Coefficient for Benthic Algal Growth	Yes	1.07
Carrying Capacity for First Order Model (gD/m2)	No	0
Respiration Rate Constant (1/day)	Yes	0.1
Temperature Coefficient for Benthic Algal Respiration	Yes	1.07
Internal Nutrient Excretion Rate Constant for Benthic Algae (1/day)	Yes	0.09
Temperature Coefficient for Benthic Algal Nutrient Excretion	Yes	1.07
Death Rate Constant (1/day)	Yes	0.05
Temperature Coefficient for Benthic Algal Death	Yes	1.07

Half Saturation Uptake Constant for Extracellular Nitrogen (mg N/L)	Yes	0.4
Half Saturation Uptake Constant for Extracellular Phosphorus (mg P/L)	Yes	0.2
Inorganic Carbon Half-Saturation Constant (not implemented) (moles/L)	No	0
LIGHT OPTION, 1=Half Saturation, 2=Smith, 3=Steele	Yes	1
Light Constant for growth (langleys/day)	Yes	1350
Benthic Algae ammonia preference (mg N/L)	Yes	0.05
Minimum Cell Quota of Internal Nitrogen for Growth (mg N/ gDW)	Yes	5
Minimum Cell Quota of Internal Phosphorus for Growth (mg P/ gDW)	Yes	3
Maximum Nitrogen Uptake Rate for Benthic Algae (mgN/ gDW-day)-	Yes	10
Maximum Phosphorus Uptake Rate for Benthic Algae (mgP/ gDW-day)-	Yes	8
Half Saturation Uptake Constant for Intracellular Nitrogen (mgN/ gDW-day)-	Yes	9
Half Saturation Uptake Constant for Intracellular Phosphorus (mgP/ gDW-day)-	Yes	5
Fraction of Benthic Algae Recycled to Organic N	Yes	0.5
Fraction of Benthic Algae Recycled to Organic P	Yes	1

Table 4-10 Constants used for Phytoplankton 1

Constants	Used	Value
Phytoplankton Detritus to Carbon ratio for Group 1 (mg D/ mg C)	No	0.0
Phytoplankton Nitrogen to Carbon ratio for Group 1 (mg N/mg C)	Yes	0.2
Phytoplankton Phosphorus to Carbon ratio for Group 1 (mg P/mg C)	Yes	0.02
Phytoplankton Carbon to Chlorophyll ratio for Group 1 (mg C/mg Chl)	Yes	50
Phytoplankton Maximum Growth Rate Constant @ 20°C for Group 1 (1/day)	Yes	3
Phytoplankton Growth Temperature Coefficient for Group 1	Yes	1.07
Phytoplankton Respiration Rate Constant @ 20°C for Group 1 (1/day)	Yes	0.5
Phytoplankton Respiration Temperature Coefficient Group 1	Yes	1.07
Phytoplankton Death Rate Constant (Non-Zoo Predation) for Group 1 (1/day)	Yes	0.04
Phytoplankton Half-Saturation Constant for N Uptake for Group 1 (mg N/L)	Yes	0.2

Phytoplankton Half-Saturation Constant for P Uptake for Group 1 (mg P/L)	Yes	0.05
Fraction of Phytoplankton Death Recycled to Organic N for Group 1	Yes	0.5
Fraction of Phytoplankton Death Recycled to Organic P for Group 1	Yes	0.5

Table 4-11 Constants used for Dissolved Oxygen

Constants	Used	Value
Oxygen to Carbon Stoichiometric Ratio	Yes	2.67
Global Reaeration Rate Constant @ 20°C (1/day)	No	0.0
Reaeration Option (Sums Wind and Hydraulic Ka)	Yes	1
Elevation above Sea Level (m)	No	0.0
Calc Reaeration Option (0= Covar, 2= Owens, 3= Churchill, 4= Tsivoglou)	Yes	3
Minimum Reaeration Rate (1/day)	No	0.0
Theta—Reaeration Temperature Correction	Yes	1.047
Theta—SOD Temperature Correction	Yes	1.074

Table 4-12 Constants used for CBOD (1) Ultimate

Constants	Used	Value
CBOD (1) Decay Rate Constant @ 20°C (1/day)	Yes	0.06
CBOD (1) Decay Rate Temperature Correction Coefficient	Yes	1.075
CBOD (1) Half Saturation Oxygen Limit (mg O2/L)	Yes	0.2
Fraction of CBOD (1) Carbon Source for Denitrification	No	0.0

4.9 Confirming Linkage of LSPC to WASP

To validate the connections made between the LSPC and the WASP model, once the linkage was made and the initial setup of the WASP water quality model was done, results from the WASP model were compared with the LSPC model. Figures 4-13 through 4-15 compare the LSPC results with the WASP results for flow, TN and TP respectively for the USGS Station 03298200.

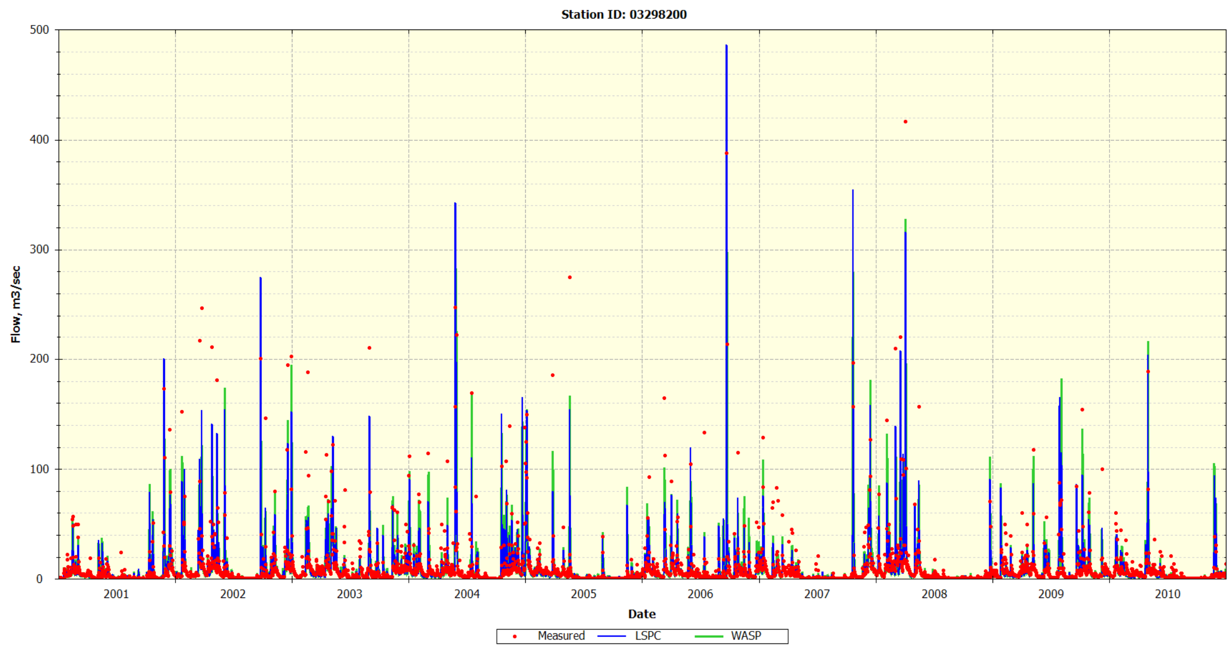

Figure 4-13 Comparison of LSPC and initial WASP results of Flow at USGS Station 03298200

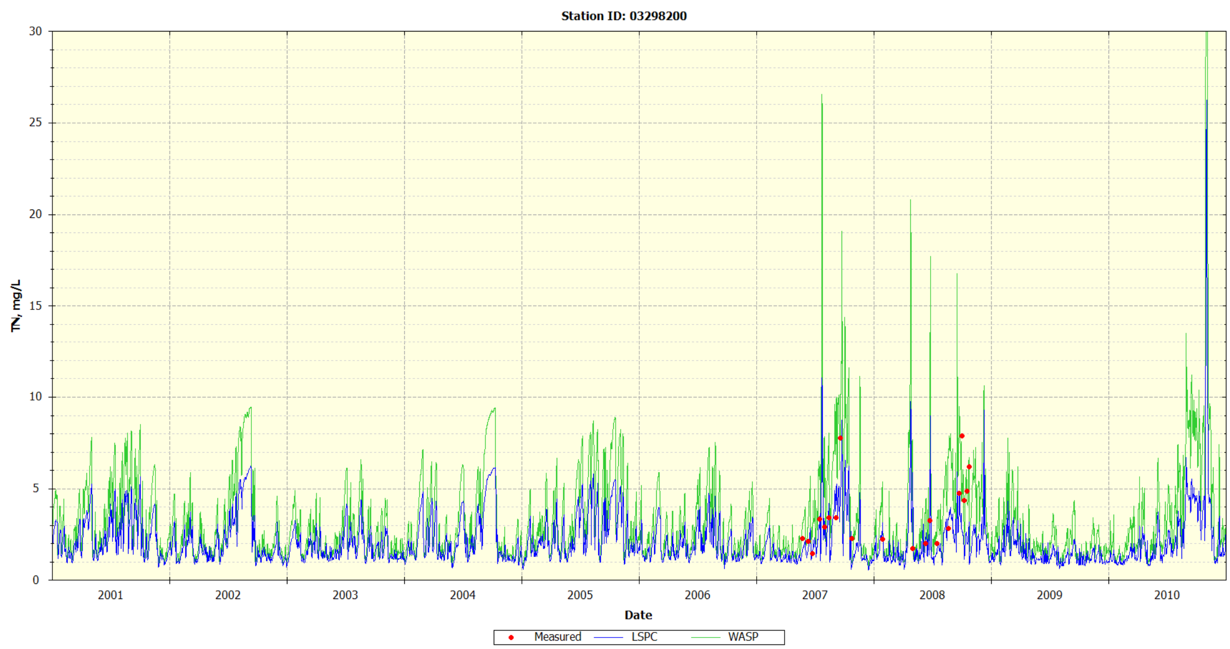

Figure 4-14 Comparison of LSPC and initial WASP results of Total Nitrogen (TN) at USGS Station 03298200

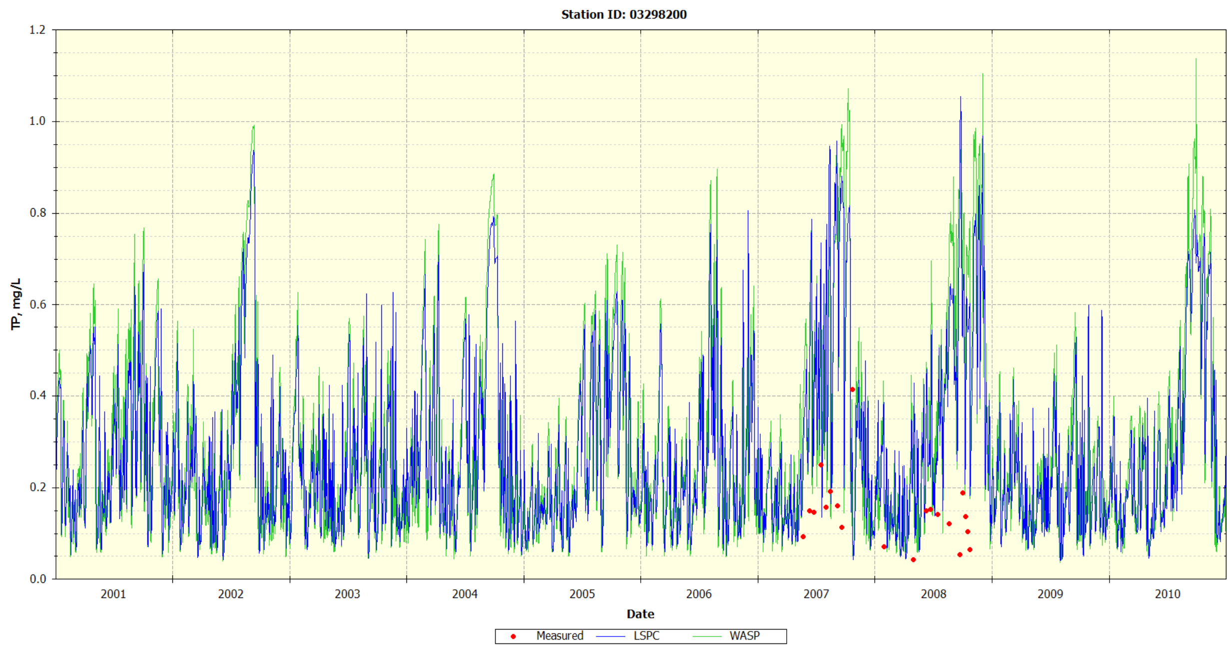

Figure 4-15 Comparison of LSPC and initial WASP results of Total Phosphorus (TP) at USGS Station 03298200

5.0 WATER QUALITY CALIBRATION

5.1 Introduction

USGS flow stations located in the Floyds Fork watershed were used to calibrate and validate the WASP water quality model. There are a total of 7 USGS flow stations in the Floyds Fork watershed that have an overlapping period of record with the model simulation. Three of the USGS flow stations contained a complete flow record for the simulation period from January 1, 2000 through December 31, 2010, three contained a nearly complete flow record for the simulation period, January 1, 2000 through December 15, 2010 and one station contained flow record for the simulation period, January 1, 2000 through September 30, 2002 and from October 1, 2005 through December 21, 2010. Five of the seven stations were used as calibration stations. Three of the calibration stations were located on the main stem of Floyds Fork (USGS 03297900, USGS 03298000 and USGS 03298200) and the other two were on the Chenoweth Run (Lower) (USGS 03298135) and on Pennsylvania Run (USGS 03298300). The remaining two stations (USGS 03298150 and USGS 03298250) were used as validation stations.

For the simulation period, water quality observations were collected approximately monthly at 26 USGS stations within the Floyds Fork watershed. The primary period of data collection was from 2007 through 2008. A majority of the USGS stations were located on the western side of Floyds Fork watershed which was dominated by point sources and urban land use. From 2000 through 2010, Jefferson County MSD collected water quality data at five stations within the Floyds Fork watershed. Three out of the 5 MSD stations were located on the main stem of Floyds Fork (EFFFF001, EFFFF002 and EFFFF003) and the remaining 2 stations on Chenoweth Run (Lower) (EFFCR001 and EFFCR002).

Data collected at the USGS stations included Temperature, DO, pH, Ammonia (NH_3), Nitrate+Nitrite (NO_X), Total Kjeldahl Nitrogen (TKN), TP, Orthophosphate (PO_4), $CBOD_5$, TSS, Conductivity and Turbidity. At the MSD stations, data was collected on Temperature, DO, pH, NH_3, NO_X, TKN, TP, PO_4, $CBOD_5$, TSS, Conductivity and Hardness.

All 26 USGS stations were used as calibration stations and the 5 MSD stations were used as validation stations. The 5 MSD stations have the same location as 5 USGS calibration stations (USGS 03297900-EFFFF001, USGS 03298200-EFFFF002, USGS 03298000-EFFFF003, USGS 03298150-EFFCR001 and USGS 03298135-EFFCR002).

Tables 5-1 and 5-2 present the hydrology and water quality calibration and validation stations and the associated WASP segments and LSPC subwatersheds. Figure 5-1 shows the location of the hydrology calibration and validation stations utilized in the WASP water quality model and Figure 5-2 shows the USGS water quality calibration stations and MSD water quality validation stations.

Table 5-1 WASP segments associated with Flow Calibration stations used in the Floyds Fork model

Location: Main Stem			
Station	**Station Name**	**WASP Segment**	**LSPC Watershed**
03297900	Floyds Fork near Peewee Valley	208	615
03298000	Floyds Fork at Fisherville	209	180
03298200	Floyds Fork near Mt. Washington	210	606
Location: Tributaries			
03298135	Chenoweth Run at Ruckriegal Parkway	140	167
03298150	Chenoweth Run at Gelhaus Lane	211	609
03298250	Cedar Creek at Thixton Road	173	134
03298300	Pennsylvania Run at Mt. Washington	181	130

Table 5-2 WASP segments associated with WQ Calibration and Validation stations used in the Floyds Fork model

Location: Main Stem				
Station	**Station Name**	**Agency**	**WASP Segment**	**LSPC Watershed**
03297830	Floyds Fork at Highway 53	USGS	40	244
03297845	Floyds Fork near Crestwood	USGS	31	229
03297900	Floyds Fork near Peewee Valley	USGS	208	615
03297930	Floyds Fork at Echo trail bridge	USGS	21	185
03298000	Floyds Fork at Fisherville	USGS	209	180
03298120	Floyds Fork at Seatonville Road	USGS	212	169
03298200	Floyds Fork near Mt. Washington	USGS	210	606
03298470	Floyds Fork near Shepherdsville	USGS	1	102
EFFFF001	Floyds Fork at Ash Avenue	MSD	208	615
EFFFF002	Floyds Fork at Bardstown Road	MSD	210	606
EFFFF003	Floyds Fork at Old Taylorsville Road	MSD	209	180
Location: Tributaries				
03297850	South Fork Curry's Fork at Moody Lane	USGS	206	220
03297855	South Fork Curry's Fork at Highway 393	USGS	73	215
03297860	North Fork Curry's Fork at Stone Ridge road	USGS	68	210
03297875	Ashers Run at Abbott lane near Crestwood	USGS	77	225
03297880	Currys Fork near Crestwood	USGS	65	617
03297950	Long Run at Old stage coach road	USGS	96	263
03297975	South Long Run at Hobbs Lane	USGS	109	274
03297980	Long Run near Fisherville	USGS	93	258
03298005	Pope lick at South poope lick road near Fisherville	USGS	118	174
03298020	Cane Run at Thurman Road	USGS	124	283
03298100	Pope lick at pope lick road near Middletown	USGS	120	178
03298110	Pope lick at Rehl road near Fisherville	USGS	119	176
03298135	Chenoweth Run at Ruckriegal Parkway	USGS	140	167
03298138	Chenoweth Run at Jeffersontown STP at Jeffersontown	USGS	138	610
03298150	Chenoweth Run at Gelhaus Lane	USGS	211	609
03298160	Chenoweth Run at Seatonville road near Jeffersontown	USGS	135	158
03298250	Cedar Creek at Thixton Road	USGS	173	134
03298300	Pennsylvania Run at Mt. Washington	USGS	181	130
EFFCR001	Chenoweth Run # 1 at Gelhaus Lane	MSD	211	609
EFFCR002	Chenoweth Run # 1 at Ruckriegal Parkway	MSD	140	167

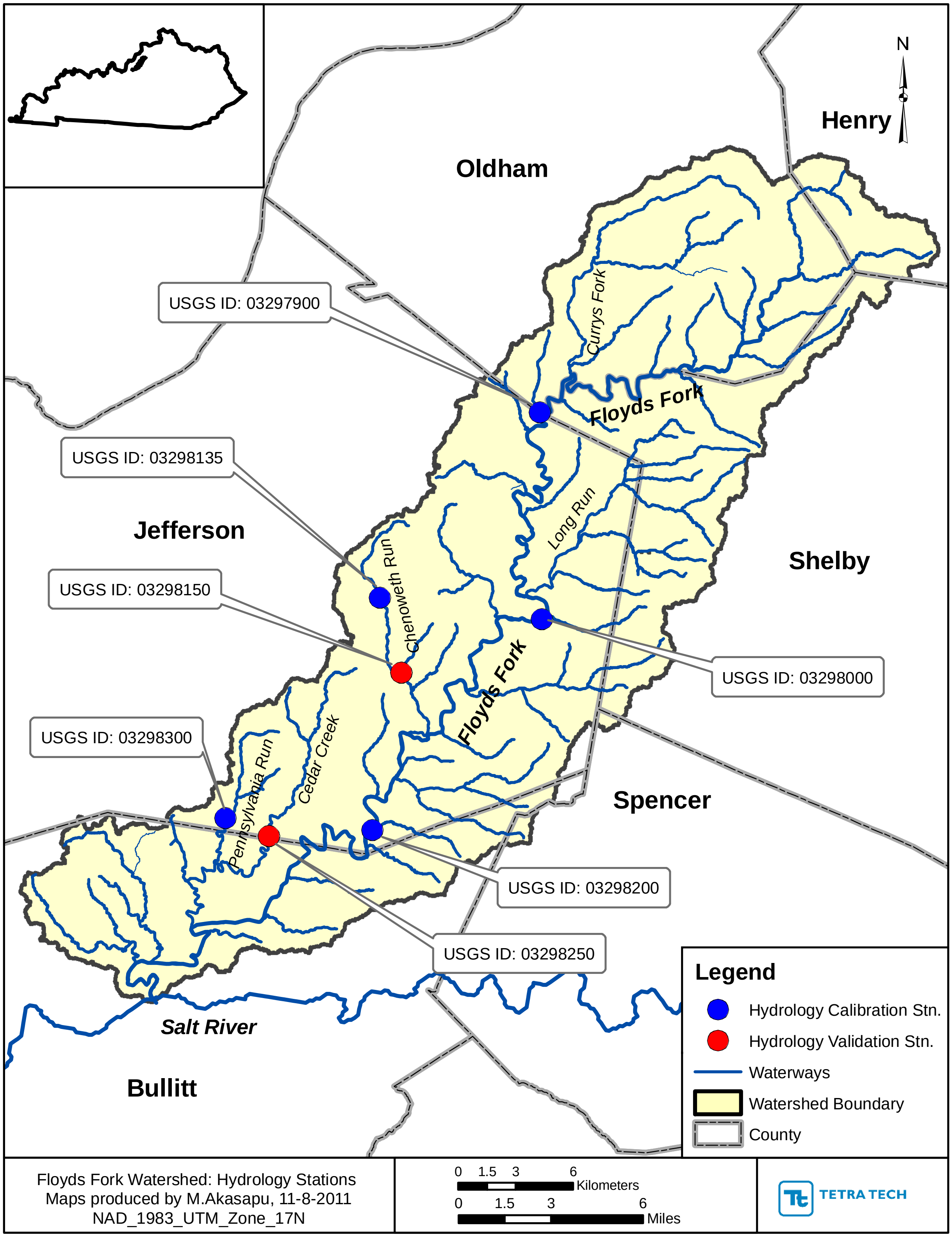

Figure 5-1 Flow Stations utilized in the WASP water quality model

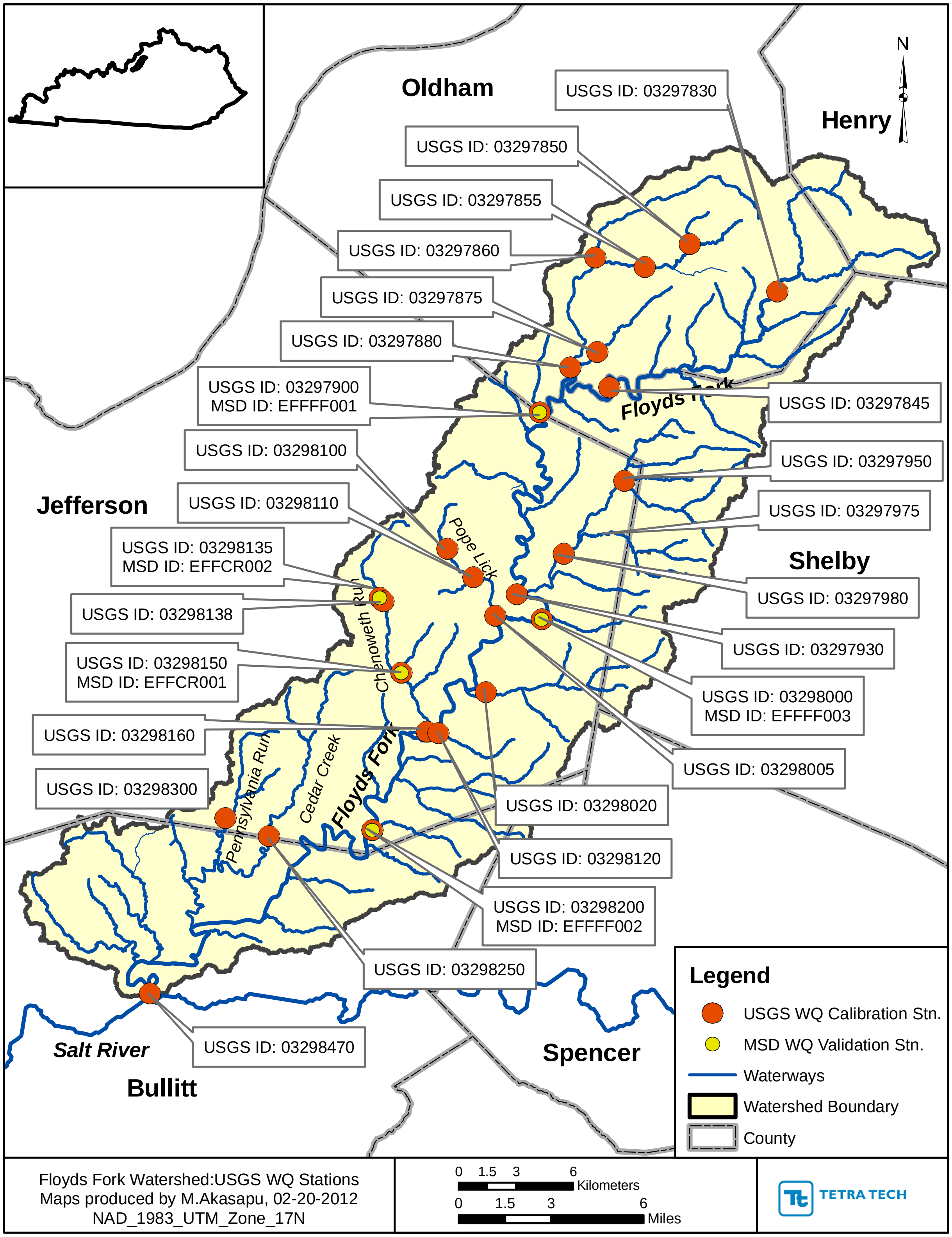

Figure 5-2 Water Quality Calibration and Validation Stations utilized in the WASP water quality model

5.2 Flow

As documented in Tetra Tech 2012, the simulated flows from the LSPC watershed model were in close range with the measured data. Therefore, very little was done for the flow calibration of the WASP water quality model. There were however, some changes made to the geometry, the depth exponents and multipliers, and the bottom roughness of the model, to fine tune the flows with respect to the measured data.

The calibration of the flows for the WASP water quality model involved comparing the simulated stream flows to the observed flows at the five USGS calibration flow stations. Validation of the flows was performed by comparing simulated flow data to observed data collected at two separate USGS flow gages.

5.2.1 Flow Conclusions

For the hydrology calibration, the observed and simulated flows were analyzed based on a quantitative statistical analysis and a set of calibration statistics. For the quantitative statistical analysis, there were 9 volume based metrics that were evaluated for the calibration. They are: Total Volume, 50% Lowest Flows, 10% Highest Flows, Seasonal Volume for Summer, Fall, Winter and Spring, Storm Volumes and Summer Storm Volumes. A qualitative grading scale (VG=Very Good, G=Good, F=Fair, and P=Poor) was developed based on the quantitative statistical analysis. A more detailed discussion of the qualitative grading scale is discussed in "Watershed Hydrology and Water Quality Modeling Report for Floyds Fork, Kentucky – REV 4" (Tetra Tech 2012).

In addition to the volume based metrics, a set of three calibration statistics between the observed and the simulated data were also evaluated, the mean, 5th percentile and 95th percentile.

Table 5-3 and 5-4 shows the score and calibration statistics respectively for each of the USGS flow gages utilized in the Floyds Fork model. The summary provided in Table 5-3 and 5-4, along with the other visual and statistical summaries indicate that the flows are well simulated in the WASP water quality model. Figure 5-5 shows the qualitative scores of the USGS flow stations spatially.

Table 5-3 Score and Grade for USGS flow gages utilized in the Floyds Fork model

USGS Station	Station Name	Qualitative score	Quantitative score
Location : Main Stem, Floyds Fork			
03297900	Floyds Fork near Peewee Valley	VG	77
03298000	Floyds Fork at Fisherville	VG	80
03298200	Floyds Fork near Mt. Washington	VG	80
Location: Tributaries			
03298135	Chenoweth Run at Ruckriegal Parkway	VG	78
03298150	Chenoweth Run at Gelhaus Lane	VG	78
03298250	Cedar Creek at Thixton Road	G	63
03298300	Pennsylvania Run at Mt. Washington	VG	75

Table 5-4 Calibration statistics for USGS flow gages utilized in the Floyds Fork model

USGS Station	Station Name	Simulated			Measured			Difference		
		Mean	5 %tile	95 %tile	Mean	5 %tile	95 %tile	Mean	5 %tile	95 %tile
Location : Main Stem, Floyds Fork										
03297900	Floyds Fork near Peewee Valley	3.65	0.11	16.69	3.92	0.04	16.57	-0.26	0.07	0.12
03298000	Floyds Fork at Fisherville	6.05	0.25	27.22	6.48	0.06	26.03	-0.43	0.19	1.19
03298200	Floyds Fork near Mt. Washington	9.06	0.47	39.62	9.95	0.34	39.56	-0.89	0.13	0.06
Location: Tributaries										
03298135	Chenoweth Run at Ruckriegal Parkway	0.30	0.03	1.29	0.30	0.01	1.36	0.00	0.02	-0.07
03298150	Chenoweth Run at Gelhaus Lane	0.75	0.15	2.70	0.78	0.12	2.95	-0.03	0.04	-0.25
03298250	Cedar Creek at Thixton Road	0.64	0.13	2.22	0.57	0.08	1.93	0.07	0.05	0.29
03298300	Pennsylvania Run at Mt. Washington	0.27	0.01	1.13	0.30	0.00	1.23	-0.04	0.01	-0.10

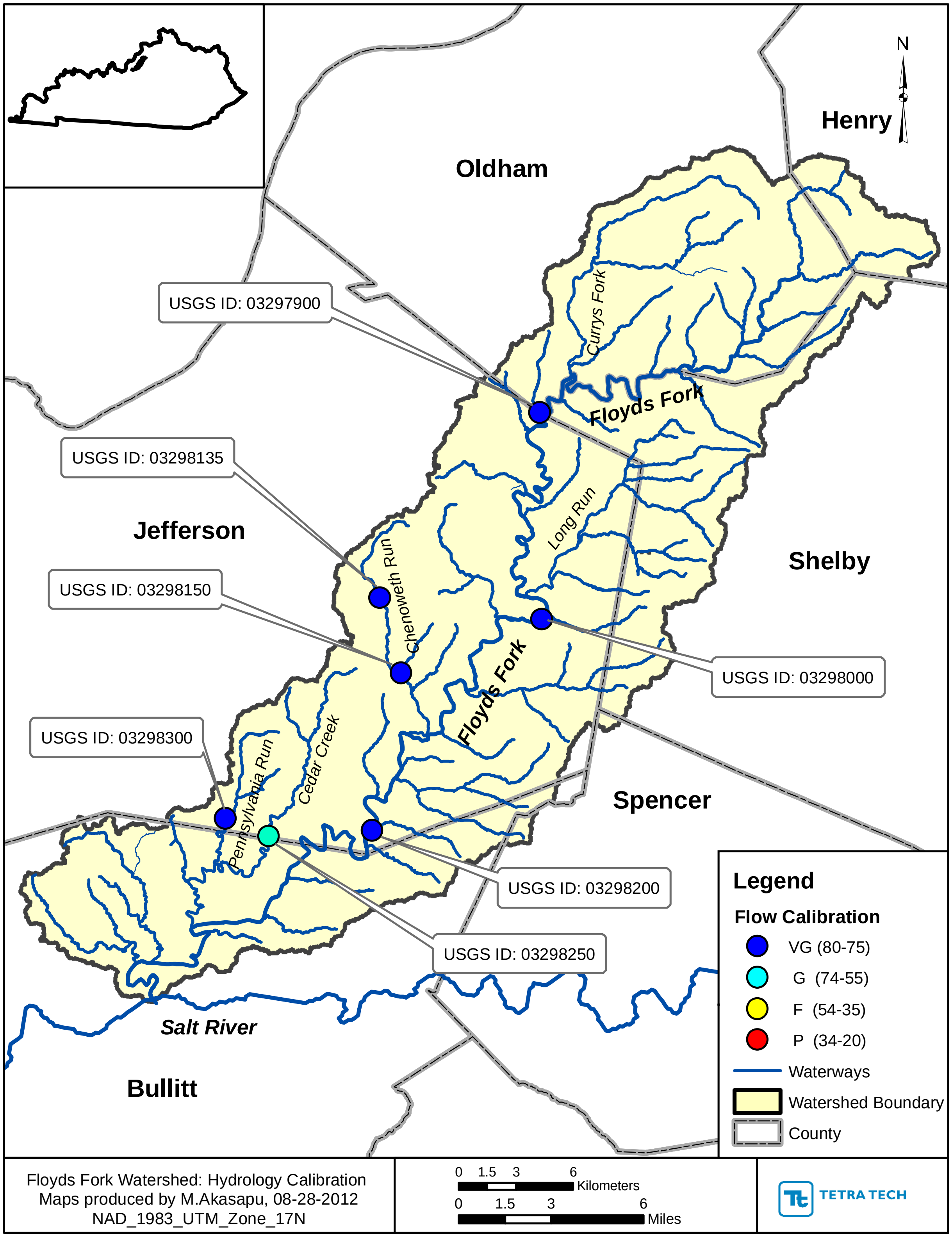

Figure 5-5 Qualitative scores of the USGS Flow stations

5.3 Water Temperature

In-stream temperature is an important parameter for simulating biochemical transformations. LSPC models in-stream temperatures by using algorithms identical to those in the Hydrologic Simulation Program FORTRAN (HSPF). The LSPC/HSPF modules used to represent water temperature include PSTEMP (soil temperature) and HTRCH (heat exchange and water temperature). A detailed description of relevant temperature algorithms is presented in the HSPF (v12) User's Manual (Bicknell et al. 2004). Water temperature (WTEMP) was not internally simulated in WASP. The simulated temperature from the LSPC watershed model was used as an input into the WASP water quality model. A more detailed discussion of the calibration of water temperature in the LSPC watershed water quality model are presented in "Watershed Hydrology and Water Quality Modeling Report for Floyds Fork, Kentucky – REV 4" (Tetra Tech 2012).

For the WASP model, all the reaches were placed in three groups based on the three weather stations assigned to the LSPC subwatersheds. For each group created, WTEMP time-series were developed by averaging the water temperatures of all the reaches within the group. This averaged WTEMP time-series was then assigned to the WASP segments that corresponded to the LSPC reaches. This methodology was used as WASP allows a maximum of four WTEMP time-series.

Figure 5-6 shows how the three temperature time-series were assigned to the WASP segments. Figures 5-7 and 5-8 present the temperature time-series at Floyds Fork in Mt. Washington at the USGS gage 03298200 and MSD station, EFFFF002 respectively. The remaining temperature time-series are presented in Appendix A.

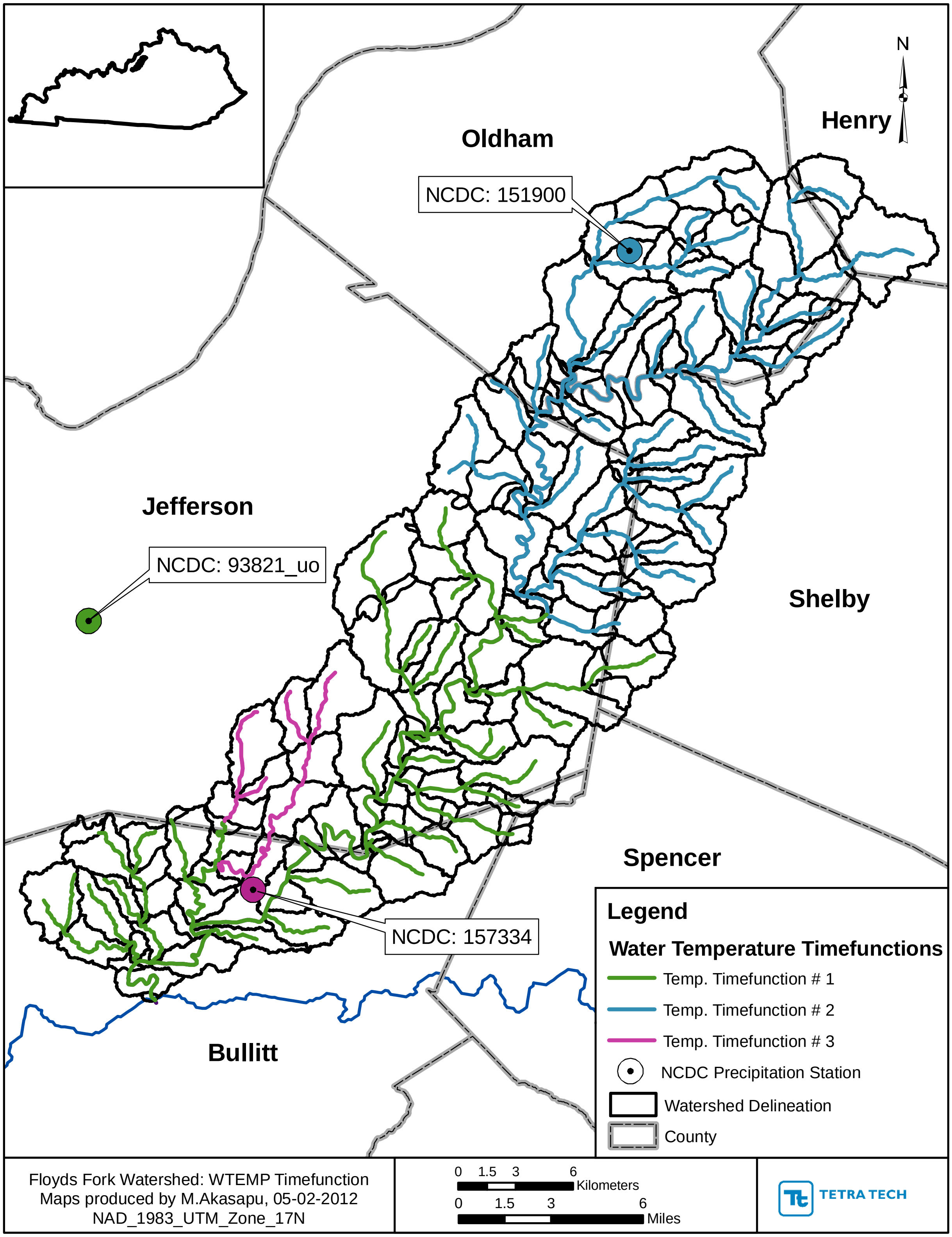

Figure 5-6 Temperature Time-series assignment

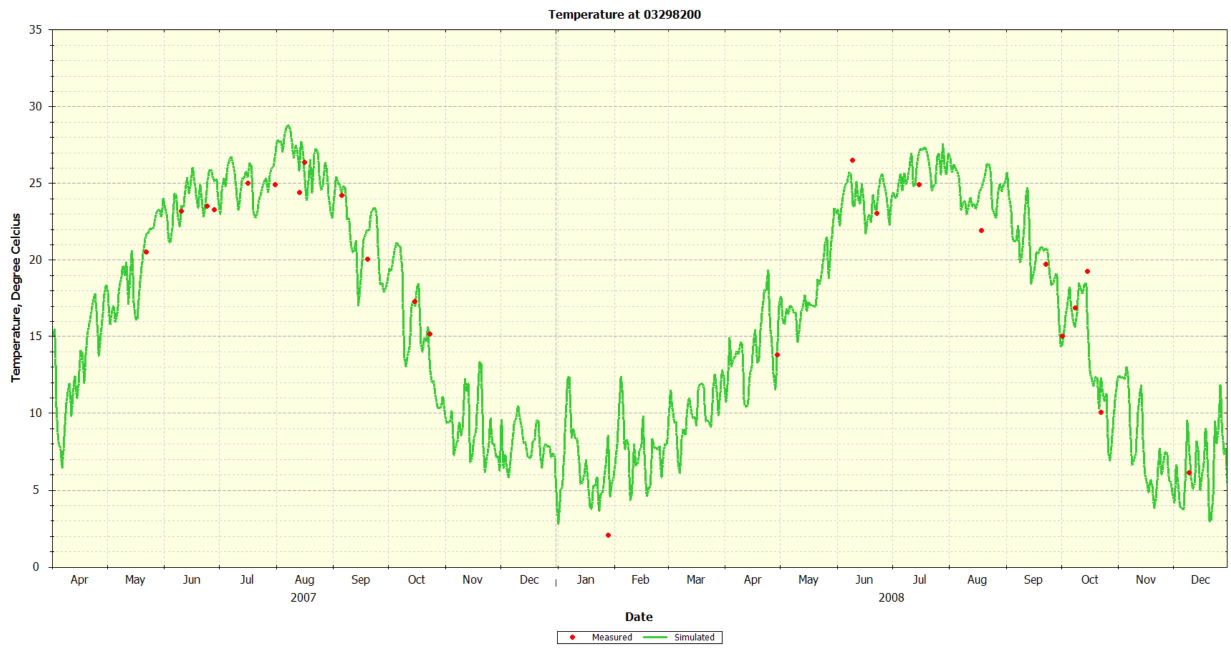

Figure 5-7 Water Temperature (WTEMP) at USGS Station 03298200

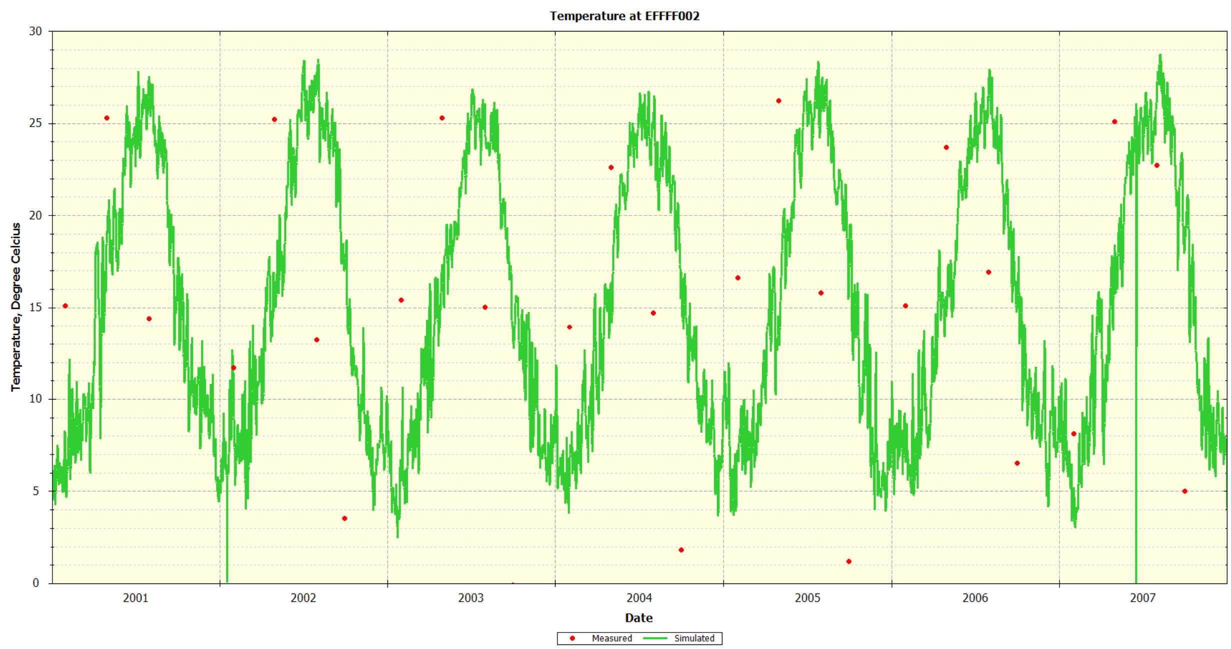

Figure 5-8 Water Temperature (WTEMP) at MSD Station EFFFF002

5.4 Dissolved Oxygen

One of the most important variables in water quality analysis is Dissolved Oxygen (DO). In WASP, DO is simulated using the EUTRO program where the balance of DO is highly influenced by processes like reaeration, nitrification, sediment oxygen demand, phytoplankton growth and respiration (EPA 2007).

In the current model, reaeration was addressed by assigning a variable reaeration rate constant (K_a) to calculate the rate based upon flow or wind, depending on whichever was larger. In addition, Churchill's formula was used to calculate the reaeration rates for all the segments. Factors like nitrification rate constant (K_{12}) and the temperature correction factor were important calibration parameters for the simulation of DO.

With the absence of site-specific SOD rates, literature values for large streams were used. SOD proved to be one of the most important calibration parameters in this model. Stoichiometric coefficients were also used to convert growth and respiration to oxygen production and respiration in the model to fine tune the balance of the DO.

Figures 5-9 and 5-10 present the DO time-series at USGS gage 03298200 and MSD station, EFFFF002 respectively. The remaining DO time-series are presented in Appendix A.

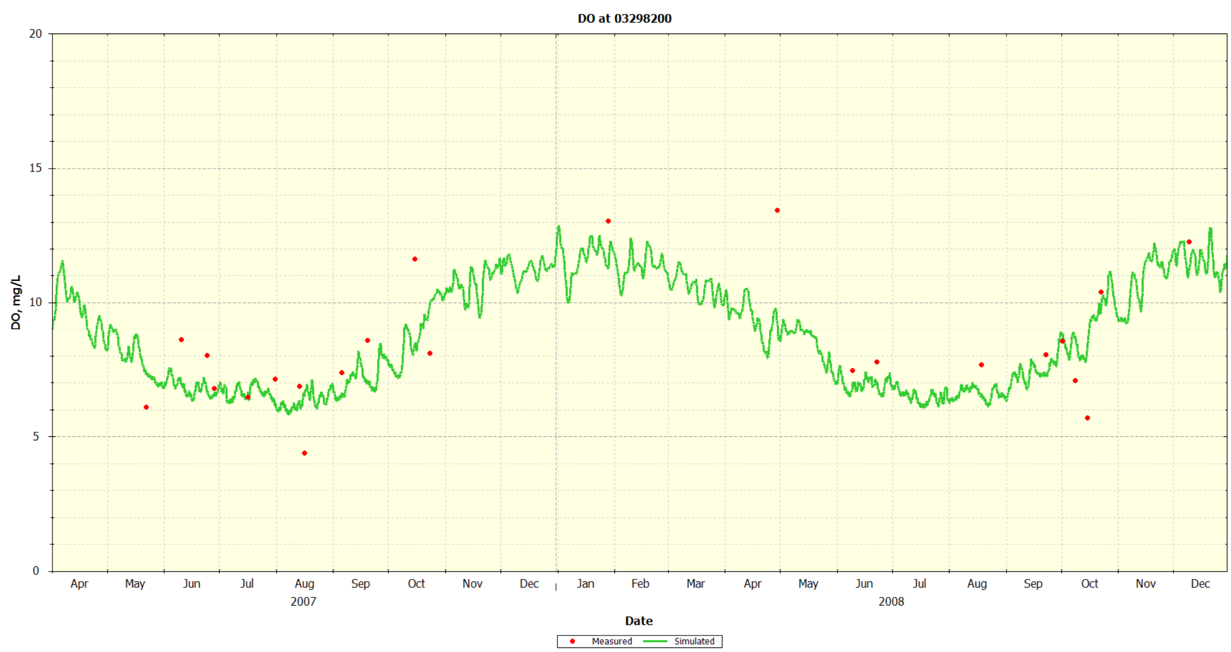

Figure 5-9 Dissolved Oxygen (DO) at USGS Station 03298200

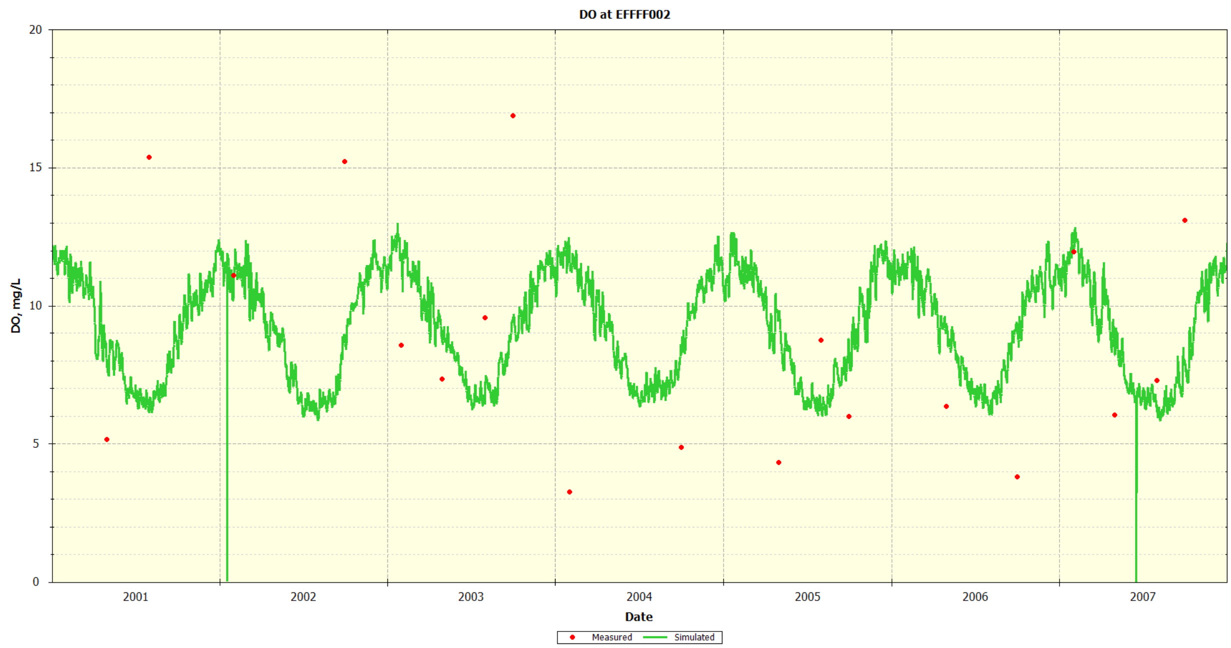

Figure 5-10 Dissolved Oxygen (DO) at MSD Station EFFFF002

5.5 Carbonaceous Biochemical Oxygen Demand

The amount of DO utilized by aquatic microbes to break the organic matter is the Biochemical Oxygen Demand (BOD) whereas Carbonaceous BOD is the oxygen demand exerted by the carbonaceous material. It is a good measure of the amount of oxygen demanding material present in water receiving both municipal and industrial wastes. To model CBOD kinetics in the current model, factors like CBOD decay rate and its respective temperature correction factor are important.

Figures 5-11 and 5-12 present the CBOD time-series at USGS gage 03298200 and MSD station, EFFFF002 respectively. The remaining CBOD time-series are presented in Appendix A.

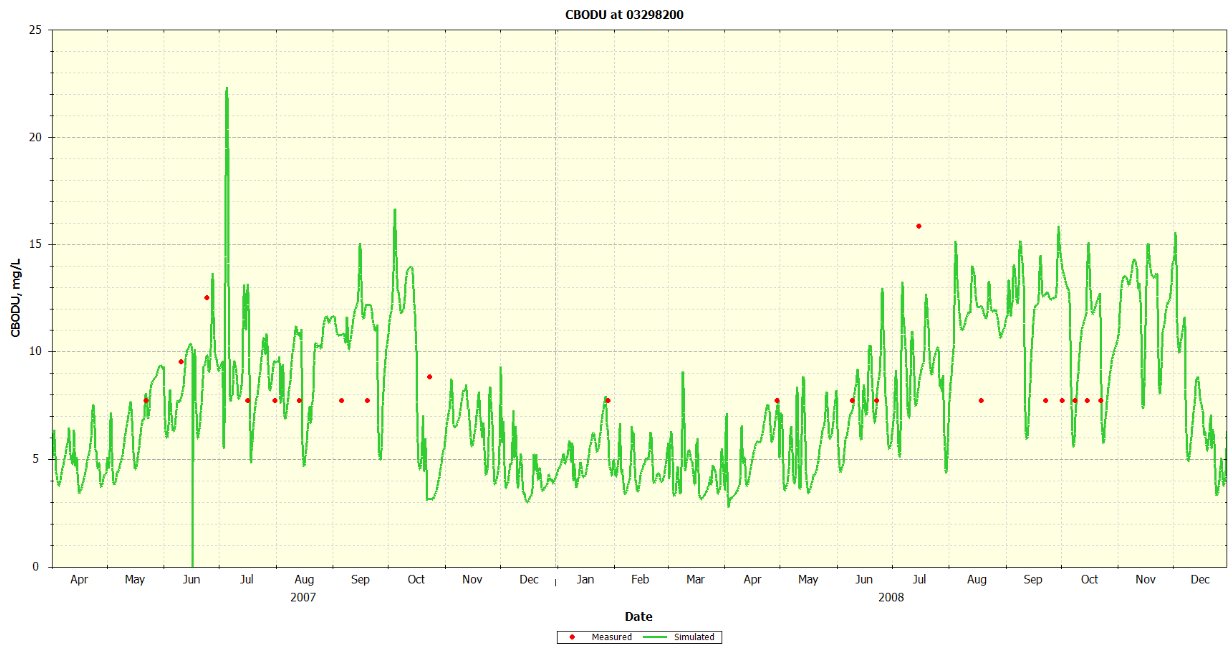

Figure 5-11 Carbonaceous Biochemical Oxygen Demand (CBOD) at USGS Station 03298200

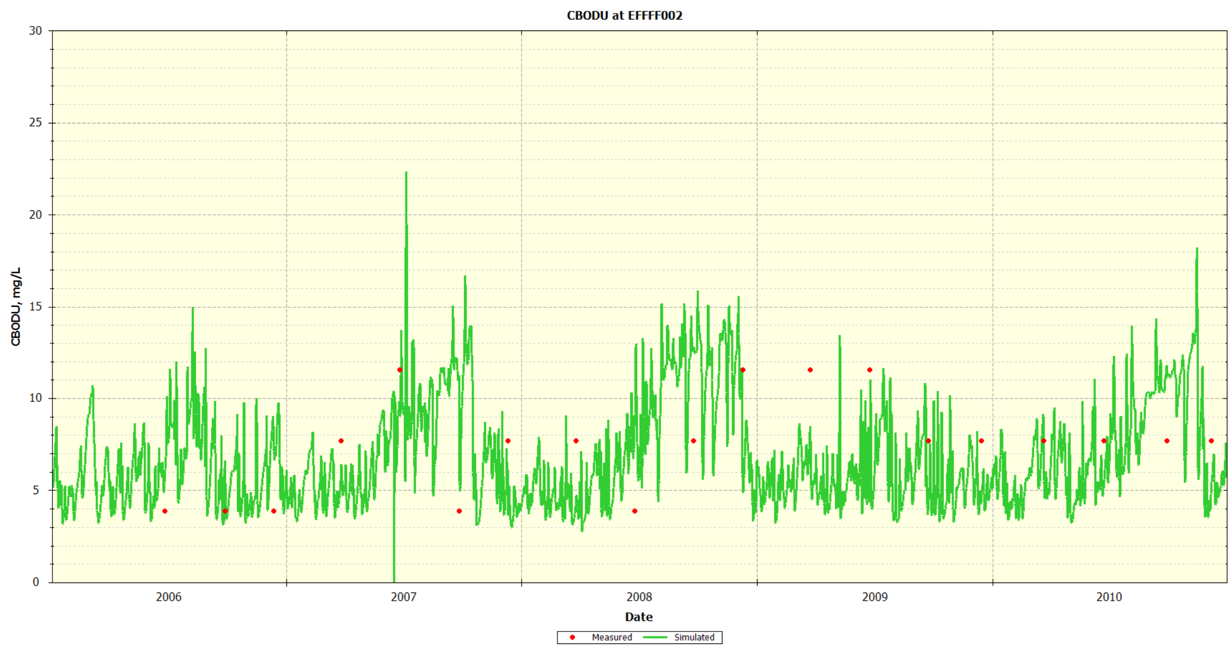

Figure 5-12 Carbonaceous Biochemical Oxygen Demand (CBOD) at MSD Station EFFFF002

5.6 Nutrients

5.6.1 Total Nitrogen

Nitrogen is an essential nutrient for the life processes of aquatic organisms making it important in water quality modeling. Nitrogen undergoes continuous internal recycling between the major forms like dissolved inorganic, dissolved organic or particulate nitrogen. Moreover, it can be added to the system through wasteloads, runoff or atmospheric deposition (EPA 1985).

Figures 5-13 and 5-14 present the TN time-series at USGS gage 03298200 and MSD station, EFFFF002 respectively. The remaining TN time-series are presented in Appendix A.

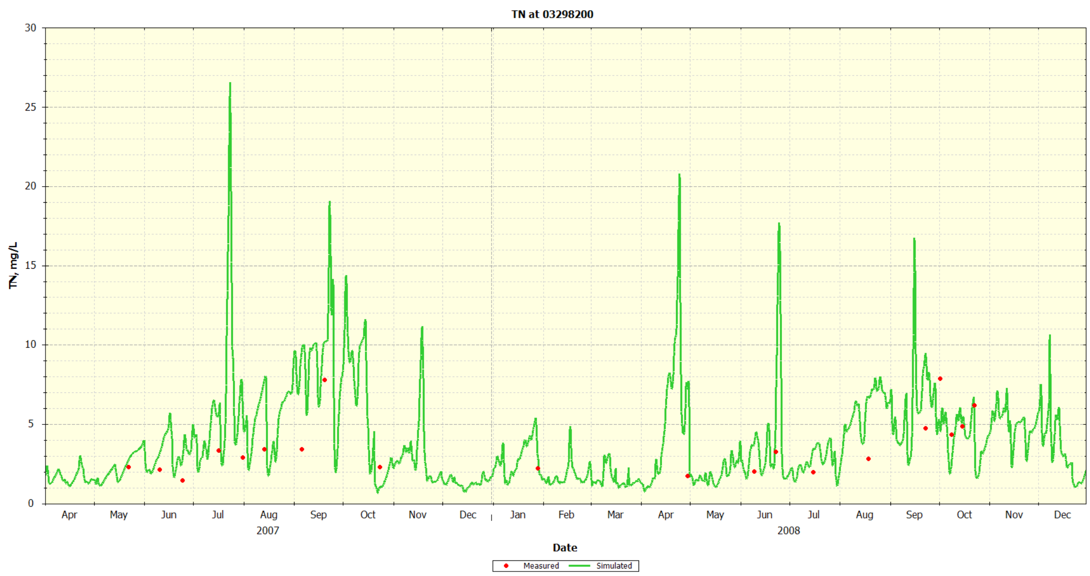

Figure 5-13 Total Nitrogen (TN) at USGS Station 03298200

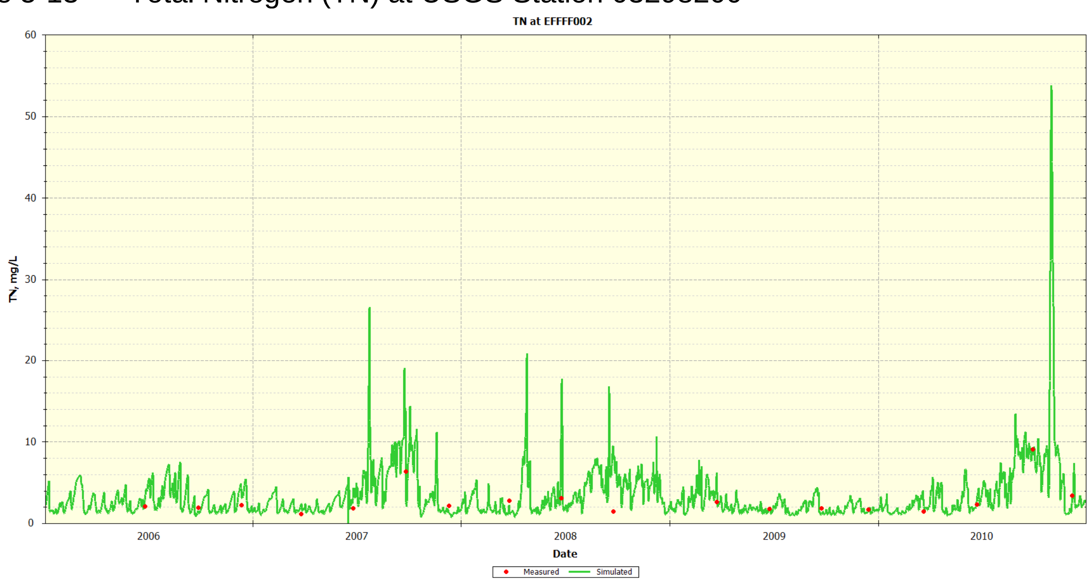

Figure 5-14 Total Nitrogen (TN) at MSD Station EFFFF002

5.6.2 Ammonia

The dynamics of nitrogen is modeled in a complex manner in WASP. It takes into account temperature dependent processes like nitrification, denitrification, mineralization, phytoplankton growth and death. These in turn affect other important water quality constituents. Nitrification and mineralization in the current model was controlled by its respective rate and temperature correction factor. In addition, the simulation of ammonia was controlled by the respiration rate of phytoplankton/benthic algae as well as the fraction of phytoplankton/benthic algae biomass that gets converted to ammonia after its death.

Figures 5-15 and 5-16 present the NH3 time-series at USGS gage 03298200 and MSD station, EFFFF002 respectively. The remaining NH3 time-series are presented in Appendix A.

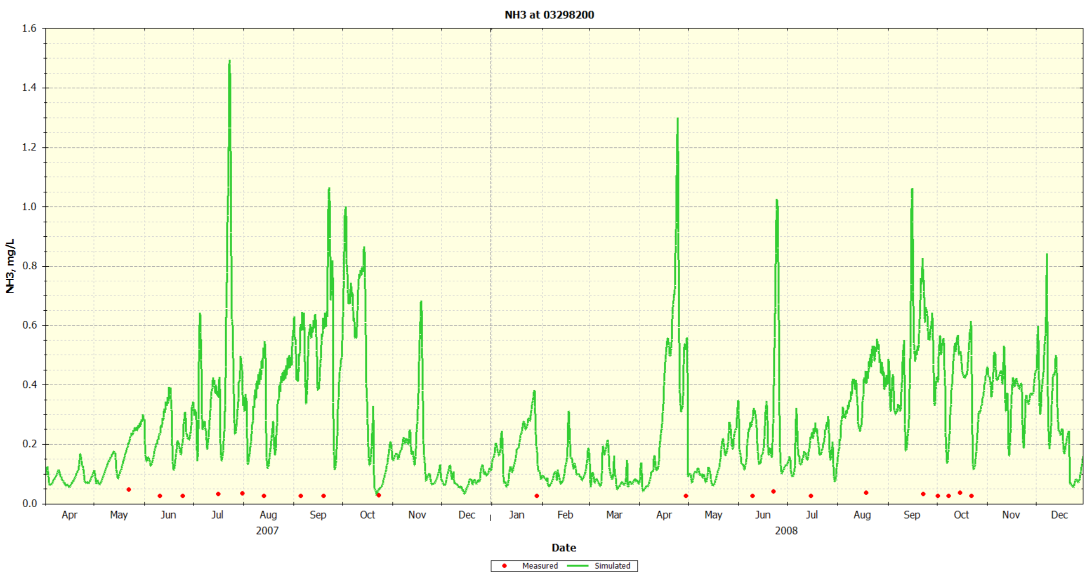

Figure 5-15 Ammonia (NH3) at USGS Station 03298200

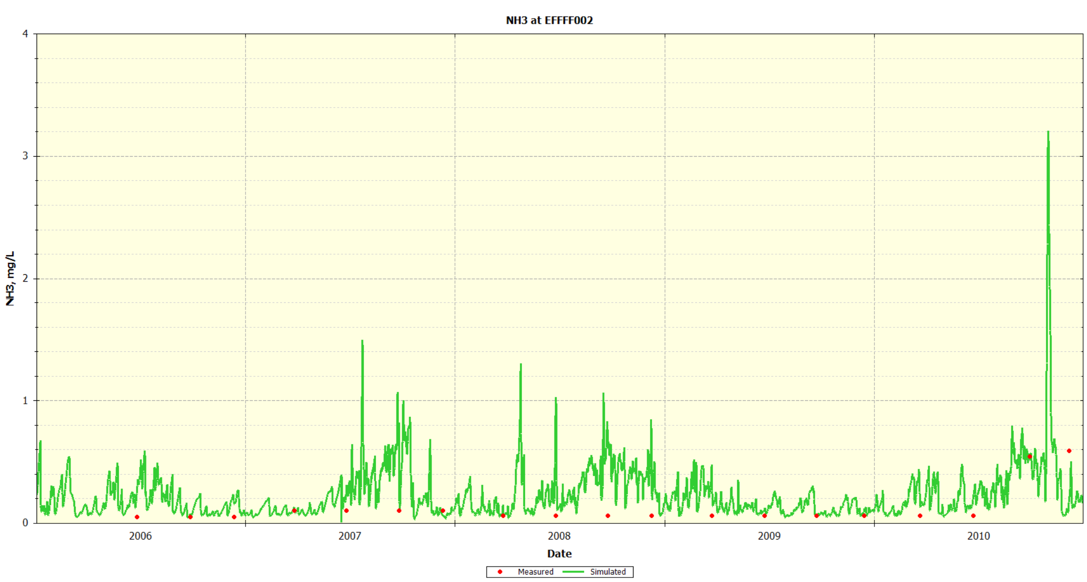

Figure 5-16 Ammonia (NH3) at MSD Station EFFFF002

5.6.3 Nitrite+Nitrate

Nitrate like ammonia is another important parameter for the growth of phytoplankton/benthic algae. Denitrification is a process that reduces nitrate to nitrogen gas in the presence of oxygen, affecting the nitrate concentration as well as oxygen production. Therefore, the simulation of nitrate was controlled by denitrification rate and its respective temperature correction factor.

Figures 5-17 and 5-18 present the NOX time-series at USGS gage 03298200 and MSD station, EFFFF002 respectively. The remaining NOX time-series are presented in Appendix A.

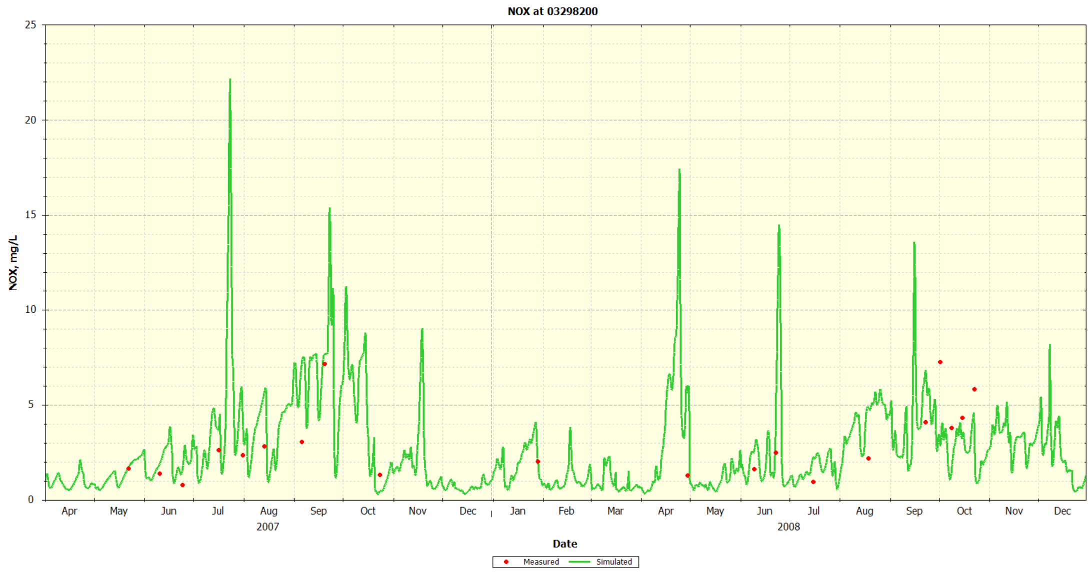

Figure 5-17 Nitrite+Nitrate (NOX) at USGS Station 03298200

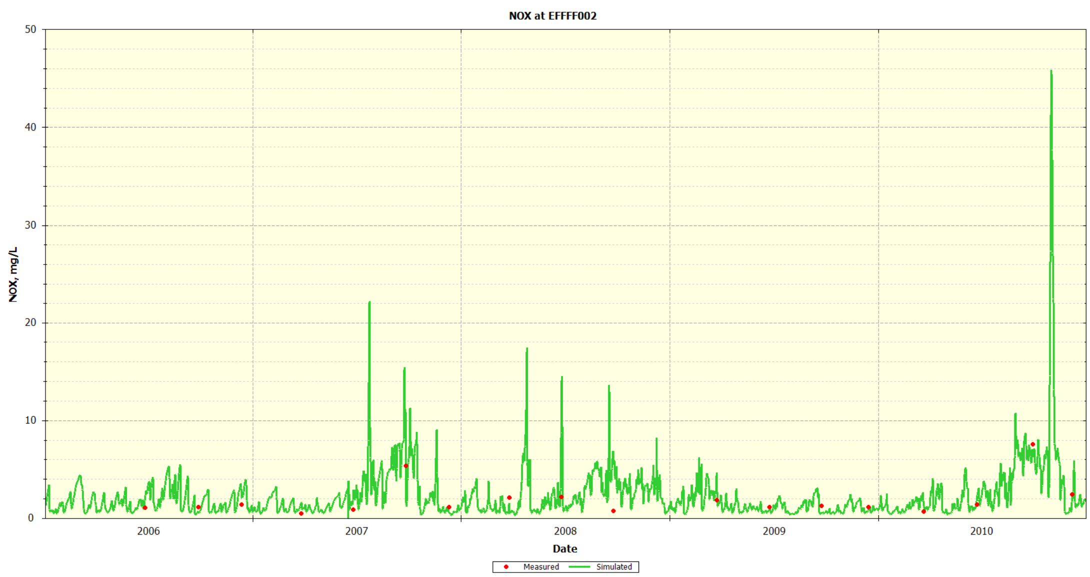

Figure 5-18 Nitrite+Nitrate (NOX) at MSD Station EFFFF002

5.6.4 Organic Nitrogen

The preferred form of nitrogen for phytoplankton/benthic algae for its growth is ammonia. Therefore, processes like mineralization help produce more ammonia by utilizing organic nitrogen for phytoplankton/benthic algae consumption. Factors related to mineralization were important since it affected the both ammonia and organic nitrogen. In addition, the fraction of phytoplankton/benthic algae getting converted to organic/inorganic forms of nitrogen was important in simulating organic nitrogen.

Figures 5-19 and 5-20 present the ORGN time-series at USGS gage 03298200 and MSD station, EFFFF002 respectively. The remaining ORGN time-series are presented in Appendix A.

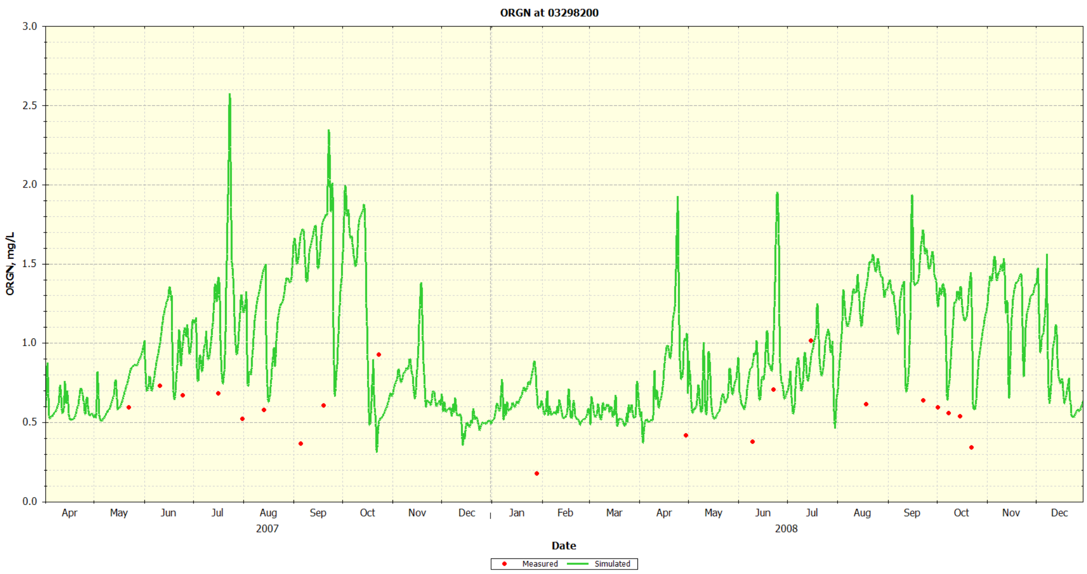

Figure 5-19 Organic Nitrogen (ORGN) at USGS Station 03298200

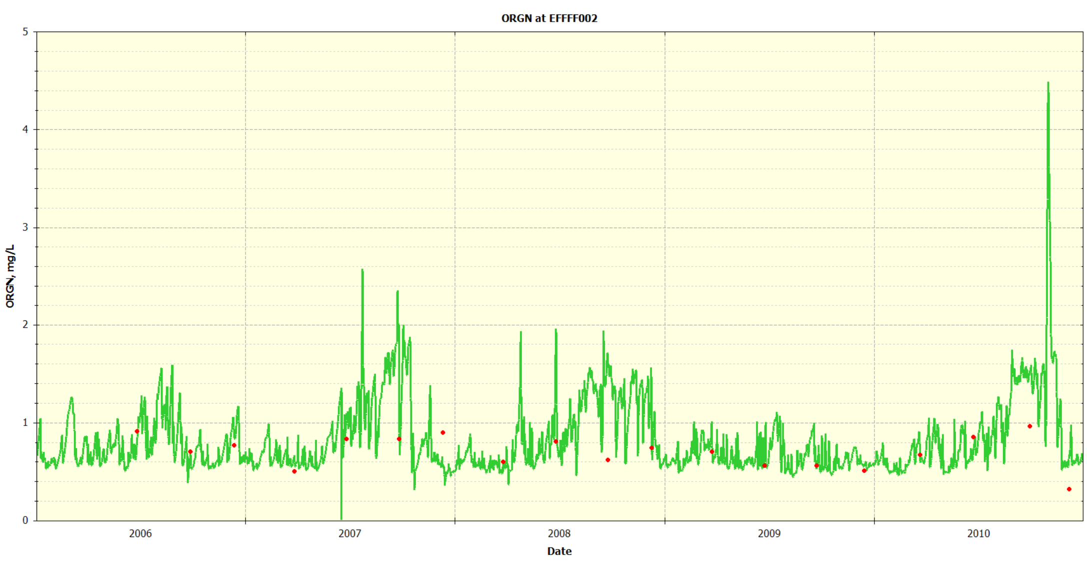

Figure 5-20 Organic Nitrogen (ORGN) at MSD Station EFFFF002

5.6.5 Total Phosphorus

Phosphorus like nitrogen is an essential nutrient for the life processes of aquatic organisms making it important in water quality modeling. It undergoes continuous internal recycling between the major forms like dissolved inorganic, dissolved organic or particulate phosphorus. Moreover, it can be added to the system through wasteloads, runoff or atmospheric deposition (EPA 1985).

Figures 5-21 and 5-22 present the TP time-series at USGS gage 03298200 and MSD station, EFFFF002 respectively. The remaining TP time-series are presented in Appendix A.

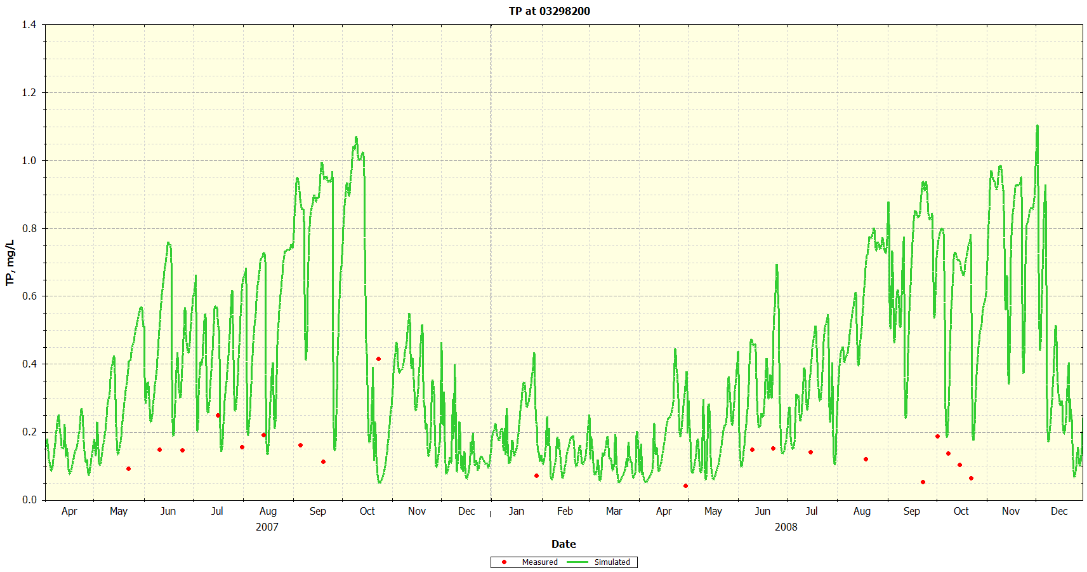

Figure 5-21 Total Phosphorus (TP) at USGS Station 03298200

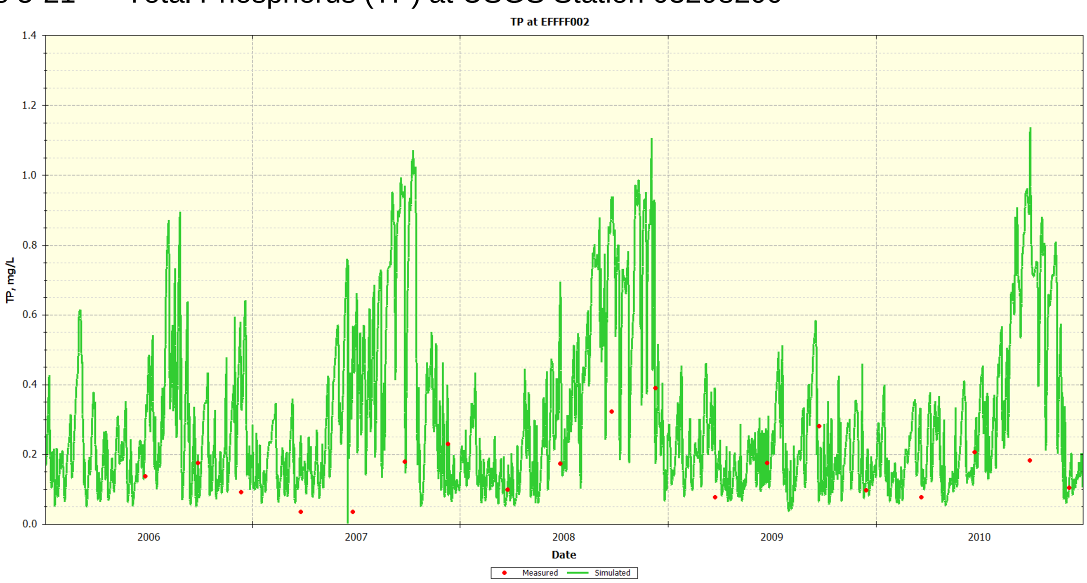

Figure 5-22 Total Phosphorus (TP) at MSD Station EFFFF002

5.6.6 Orthophosphate

Similar to the nitrogen cycle discussed in the previous sections, the phosphorus cycle functions in a similar manner. Orthophosphate like ammonia and nitrate is an inorganic form of phosphorus and is beneficial for the growth of phytoplankton/benthic algae. Mineralization in the phosphorus cycle converts organic phosphorus to the inorganic form before utilization by phytoplankton.

Therefore, the simulation of orthophosphate was controlled by the process of mineralization with the associated temperature correction factor and the fraction of phytoplankton death converted to organic phosphorus.

Figures 5-23 and 5-24 present the PO4 time-series at USGS gage 03298200 and MSD station, EFFFF002 respectively. The remaining PO4 time-series are presented in Appendix A.

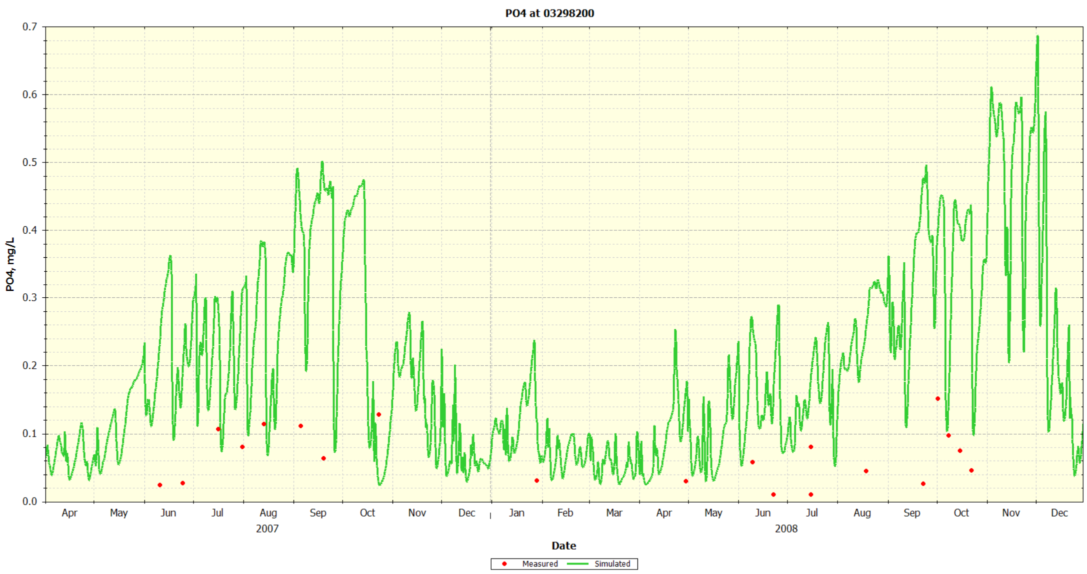

Figure 5-23 Orthophosphate (PO4) at USGS Station 03298200

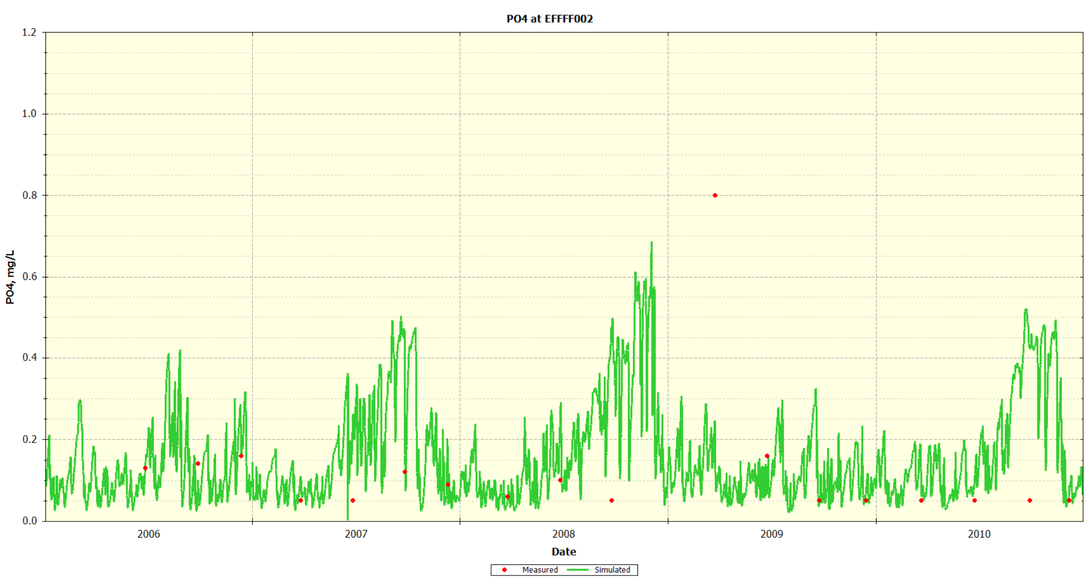

Figure 5-24 Orthophosphate (PO4) at MSD Station EFFFF002

5.6.7 Organic Phosphorus

The simulation of organic phosphorus was controlled by the same processes and same factors as described in Section 5.6.6.

Figures 5-25 and 5-26 present the ORGP time-series at USGS gage 03298200 and MSD station, EFFFF002 respectively. The remaining ORGP time-series are presented in Appendix A.

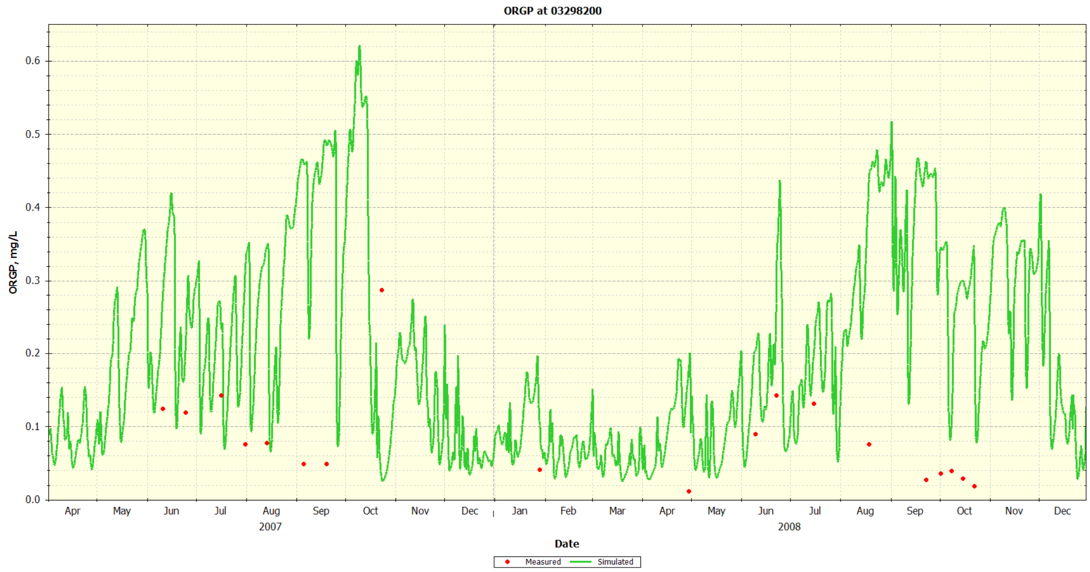

Figure 5-25 Organic Phosphorus (ORGP) at USGS Station 03298200

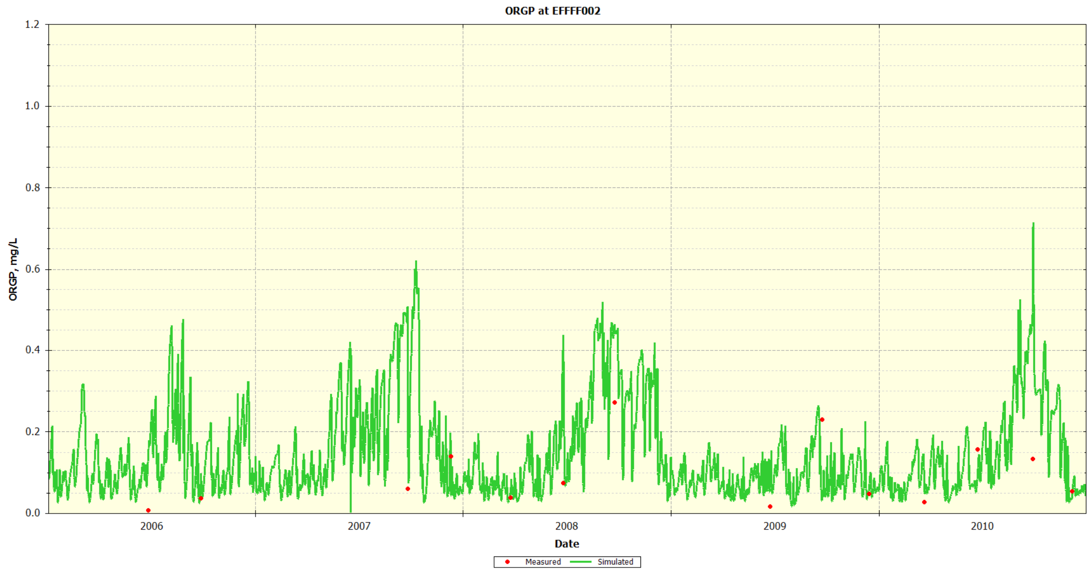

Figure 5-26 Organic Phosphorus (ORGP) at MSD Station EFFFF002

5.7 Sediments

The simulated sediments from the LSPC watershed model were in close range with the measured data. Therefore, very little was done to the simulation of sediments of the WASP water quality model.

Figures 5-27 and 5-28 present the sediments time-series at USGS gage 03298200 and MSD station, EFFFF002 respectively. The remaining sediments time-series are presented in Appendix A.

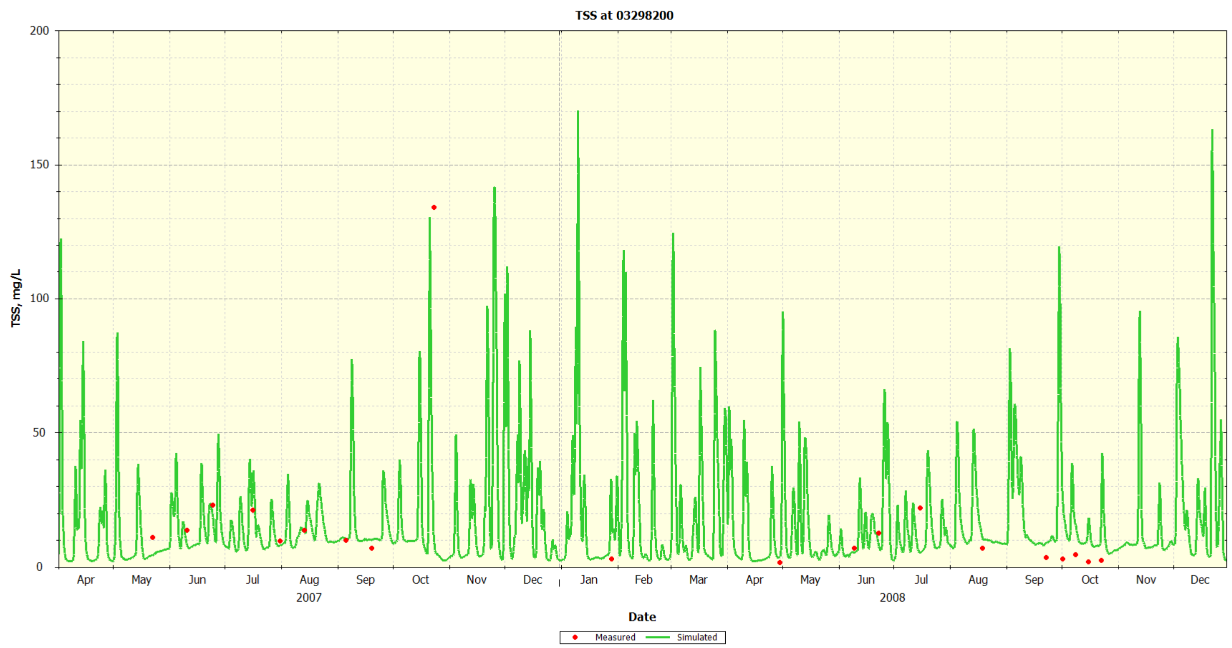

Figure 5-27 Total Suspended Sediments at USGS Station 03298200

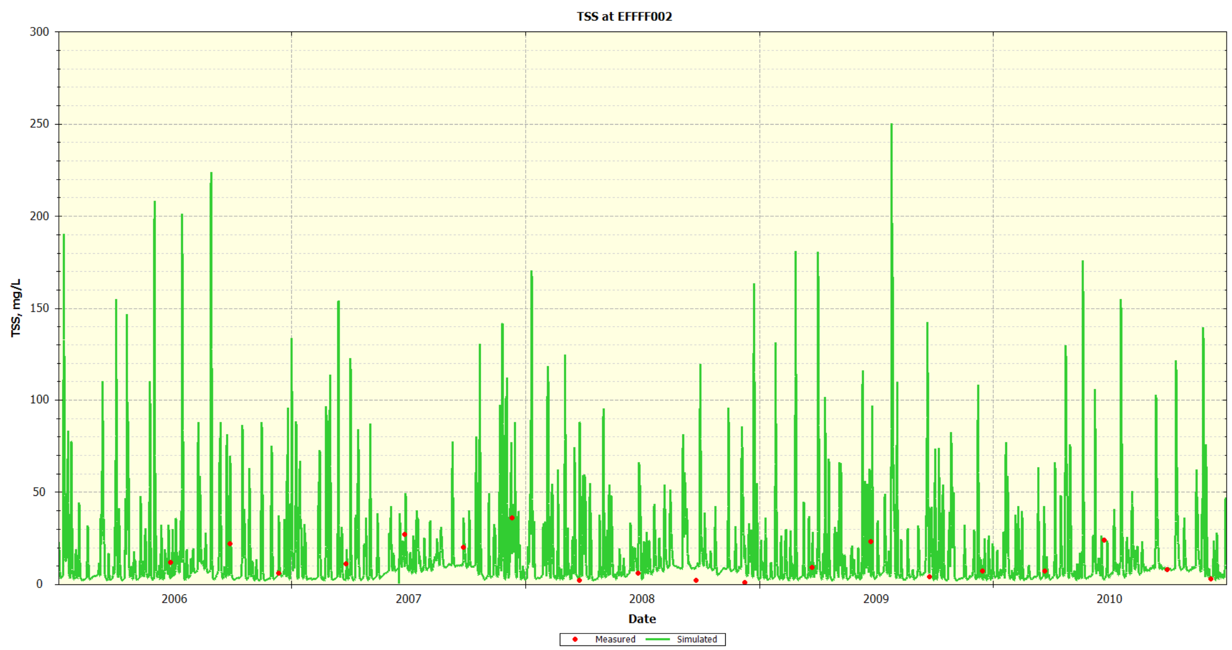

Figure 5-28 Total Suspended Sediments at MSD Station EFFFF002

5.8 pH

A constant value for pH and alkalinity was provided for all the segments based on the observed data at the water quality stations. These concentrations were further modified with respect to its performance against the measured data.

Figures 5-29 and 5-30 present the pH time-series at USGS gage 03298200 and MSD station, EFFFF002 respectively. The remaining pH time-series are presented in Appendix A.

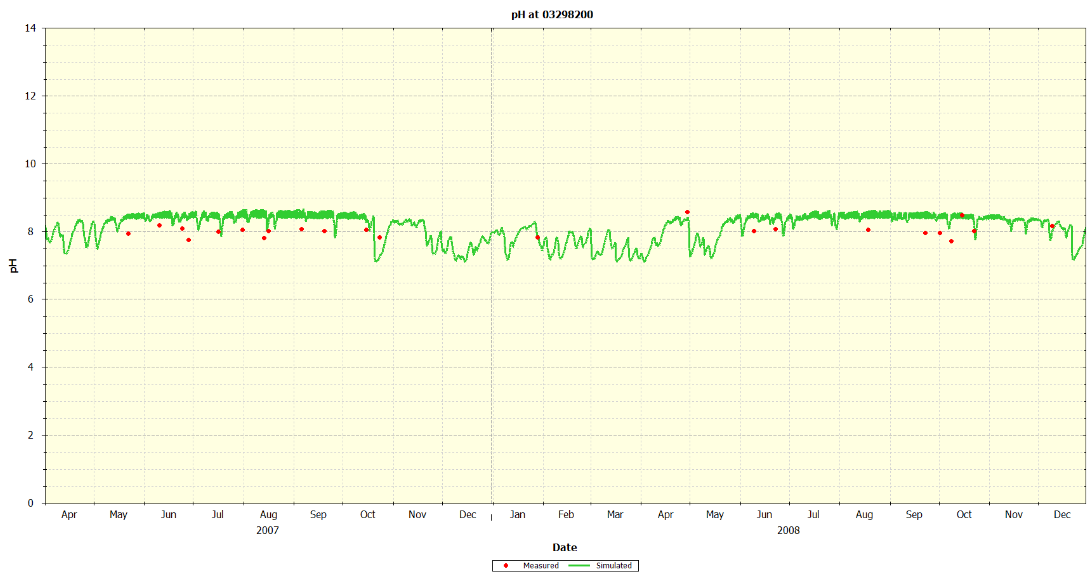

Figure 5-29 pH at USGS Station 03298200

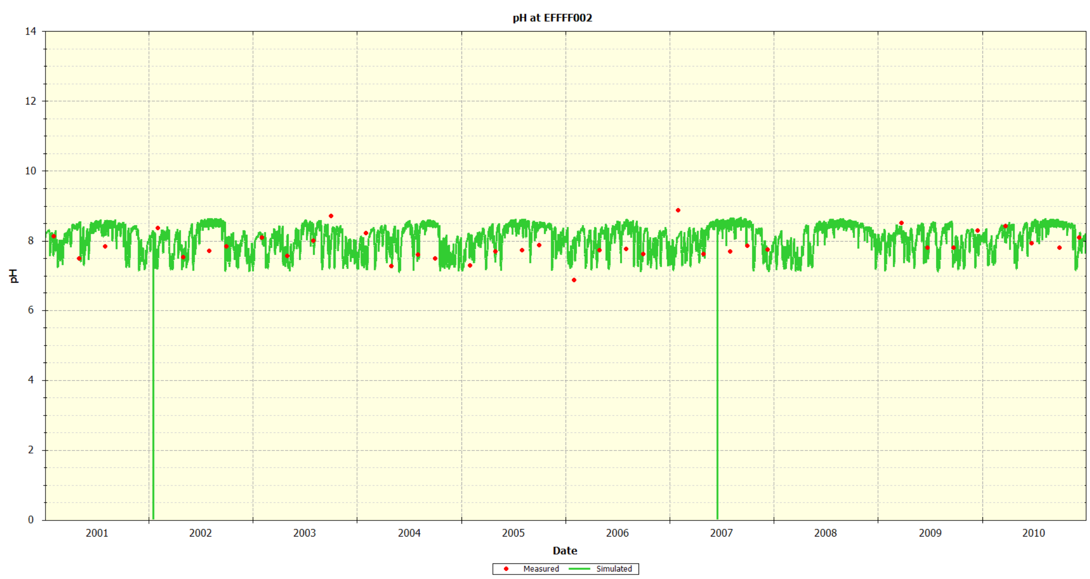

Figure 5-30 pH at MSD Station EFFFF002

5.9 Chlorophyll-a

The measure to characterize the phytoplankton biomass is Chlorophyll-a. WASP has the ability to compute phytoplankton chlorophyll-a concentration based on carbon to chlorophyll-a mechanism which in return can be compared with the measured data.

KDOW provided measured data for chlorophyll-a for the year 2010 for few stations. The averaged chlorophyll-a concentration was supplied at all the boundary conditions depending on the water quality stations with data. The concentration ranged from 0.7 to 9.0 µg/L.

Figures 5-31 present the Chlorophyll-a time-series at USGS gage 03298200. The remaining Chlorophyll-a time-series are presented in Appendix A.

Figure 5-31 Chlorophyll-a (CHLA) at USGS Station 03298200

6.0 SUMMARY AND CONCLUSIONS

6.1 Water Quality Observations and Conclusions

The WASP water quality model simulated DO very well at most stations. There were a few locations where the LSPC watershed model did not have low DO concentration in the summertime or high DO concentrations during wintertime and this was translated into the WASP model. This was improved in the WASP model by adjusting the sediment oxygen demand in those segments. Generally speaking, the WASP model DO calibration is very good.

The measured data for CBOD was expressed in milligrams of oxygen per liter of sample during 5 days of incubation at 20 °C. The measured data was converted to CBOD ultimate to compare to the simulated data. Much of the measured CBOD ultimate data was at or below the method of detection limit of 7.70 mg/l. With this in mind, the goal was to try to simulate CBOD concentrations in and around 7.70 mg/l. Although the model over predicts in some of the WQ stations, the model does a fairly good job at simulating CBOD less than 7.70 mg/l.

TN and TP were simulated fairly well in the LSPC watershed model as the focus of the watershed model calibration for TN and TP was to properly represent the magnitudes and to capture the trends of the nutrients entering Floyds Fork. However, there were few stations in this category that did not capture the nutrient loads as well as the rest. The water quality stations dominated by point sources often resulted in high concentrations compared to the measured data. However, these stations captured the trend of the measured data well. This was especially true for TP. The high concentrations in these stations could be associated with the defaults assumed for the point sources with no quantifiable data.

Therefore, with the totals (TN and TP) capturing the trends and magnitudes fairly well, the main focus for the WASP nutrient calibration was on the simulation of the nutrient species. The simulation of the nutrient species posed challenges especially with the internal recycling among them. This was due to the high totals at the water quality stations dominated by the point sources. For nitrogen species, organic nitrogen does very well in capturing the trend as well as the magnitude at the water quality stations dominated by non-point discharges. Nitrate and ammonia were a little high at the stations that were dominated by point sources, the trends and magnitudes were captured fairly well at all stations dominated by the non-point discharges. The high ammonia/nitrate concentration could be attributed to the high TN concentration from the LSPC watershed model and the way TN was distributed among the species due to the representation of point sources. Among the phosphorus species orthophosphate does very well in capturing the trends and magnitudes with respect to the measured data. However, the simulated organic phosphorus is a little high compared to the measured data at stations dominated by point sources. This could be attributed to the internal recycling of already high TP concentrations at those stations.

The model does very well in simulating pH compared to the measured data at all calibration and validation stations. pH seems to be in perfect range with the measured data.

At all the USGS calibration stations the model properly captures the trends and the magnitudes of the sediments during low flow events. The peaks at high flow events were also captured well. The model simulated low suspended sediment concentrations almost all of the time except for when rain events came through and washed some sediment into the streams. Without having monitored data during these times of sediment delivery to the stream, it is hard to determine how well the model is capturing this process.

Similar to hydrology, a qualitative ranking (VG=Very Good, G=Good, F=Fair, and P=Poor) was developed based on the quantitative analysis of comparing simulated and observed loads. However, unlike hydrology, there were not 9 error statistics for comparison and calculation. Instead, the average annual simulated and observed loads for the nutrients was computed for the period of record. The absolute percentage error was then estimated based on the average annual simulated and observed loads and compared to the criteria set for the water quality calibration for the qualitative grading ranking. A more detailed discussion of the qualitative grading scale is discussed in “Watershed Hydrology and Water Quality Modeling Report for Floyds Fork, Kentucky – REV 4” (Tetra Tech 2012).

In addition to absolute percentage error, a set of three calibration statistics between the observed and the simulated data were also evaluated, the mean, 5^{th} percentile and 95^{th} percentile. Based on the quantitative scores and the calibration statistics, the model performs well.

Tables 6-1 and 6-2 show the score and grade for each of the USGS water quality calibration and MSD validation station for TN and TP loads. Table 6-3 and 6-4 show the calibration statistics for all the water quality calibration and validation stations for TN and TP respectively. The summary provided in these tables along with the other visual and statistical summaries presented in Appendix A indicate that the water quality model should perform well for the intended purpose.

Figure 6-1, 6-2, 6-3 and 6-4 shows the qualitative scores of the USGS water quality calibration and MSD validation stations for TN and TP respectively.

Table 6-1 Score and Grade for TN for USGS WQ Calibration and MSD Validation Stations utilized in the Floyds Fork model

Station	Station Name	Qualitative score	Quantitative score
Location: Main Stem, Floyds Fork			
03297830	Floyds Fork at Highway 53	G	44
03297845	Floyds Fork near Crestwood	G	48
03297900	Floyds Fork near Peewee Valley	G	43
03297930	Floyds Fork at Echo trail bridge	G	66
03298000	Floyds Fork at Fisherville	G	46
03298120	Floyds Fork at Seatonville Road	G	44
03298200	Floyds Fork near Mt. Washington	G	46
03298470	Floyds Fork near Shepherdsville	G	40
EFFFF001	Floyds Fork at Ash Avenue	VG	17
EFFFF002	Floyds Fork at Bardstown Road	G	60
EFFFF003	Floyds Fork at Old Taylorsville Road	G	41
Location: Tributaries			
03297850	South Fork Curry's Fork at Moody Lane	G	69
03297855	South Fork Curry's Fork at Highway 393	VG	26
03297860	North Fork Curry's Fork at Stone Ridge road	G	56
03297875	Ashers Run at Abbott lane near Crestwood	G	48
03297880	Currys Fork near Crestwood	VG	24
03297950	Long Run at Old stage coach road	VG	24
03297975	South Long Run at Hobbs Lane	VG	15
03297980	Long Run near Fisherville	VG	20
03298005	Pope lick at South poope lick road near Fisherville	VG	4
03298020	Cane Run at Thurman Road	VG	20
03298100	Pope lick at pope lick road near Middletown	G	37
03298110	Pope lick at Rehl road near Fisherville	VG	28
03298135	Chenoweth Run at Ruckriegal Parkway	VG	4
03298138	Chenoweth Run at Jeffersontown STP at Jeffersontown	G	62
03298150	Chenoweth Run at Gelhaus Lane near Fern creek	G	59
03298160	Chenoweth Run at Seatonville road near Jeffersontown	G	34
03298250	Cedar Creek at Thixton Road	G	54
03298300	Pennsylvania Run at Mt. Washington	G	43
EFFCR001	Chenoweth Run # 1 at Gelhaus Lane	G	45
EFFCR002	Chenoweth Run # 1 at Ruckriegal Parkway	F	77

Table 6-2 Score and Grade for TP for USGS WQ Calibration and MSD Validation Stations utilized in the Floyds Fork model

Station	Station Name	Qualitative score	Quantitative score
Location: Main Stem, Floyds Fork			
03297830	Floyds Fork at Highway 53	VG	30
03297845	Floyds Fork near Crestwood	F	73
03297900	Floyds Fork near Peewee Valley	G	69
03297930	Floyds Fork at Echo trail bridge	F	75
03298000	Floyds Fork at Fisherville	G	44
03298120	Floyds Fork at Seatonville Road	G	57
03298200	Floyds Fork near Mt. Washington	VG	1
03298470	Floyds Fork near Shepherdsville	VG	24
EFFFF001	Floyds Fork at Ash Avenue	G	42
EFFFF002	Floyds Fork at Bardstown Road	G	48
EFFFF003	Floyds Fork at Old Taylorsville Road	VG	23
Location: Tributaries			
03297850	South Fork Curry's Fork at Moody Lane	F	70
03297855	South Fork Curry's Fork at Highway 393	VG	10
03297860	North Fork Curry's Fork at Stone Ridge road	F	77
03297875	Ashers Run at Abbott lane near Crestwood	G	51
03297880	Currys Fork near Crestwood	G	42
03297950	Long Run at Old stage coach road	VG	12
03297975	South Long Run at Hobbs Lane	G	61
03297980	Long Run near Fisherville	G	62
03298005	Pope lick at South poope lick road near Fisherville	G	48
03298020	Cane Run at Thurman Road	G	49
03298100	Pope lick at pope lick road near Middletown	G	50
03298110	Pope lick at Rehl road near Fisherville	G	36
03298135	Chenoweth Run at Ruckriegal Parkway	G	69
03298138	Chenoweth Run at Jeffersontown STP at Jeffersontown	G	59
03298150	Chenoweth Run at Gelhaus Lane near Fern creek	G	34
03298160	Chenoweth Run at Seatonville road near Jeffersontown	VG	20
03298250	Cedar Creek at Thixton Road	VG	0
03298300	Pennsylvania Run at Mt. Washington	G	47
EFFCR001	Chenoweth Run # 1 at Gelhaus Lane	VG	30
EFFCR002	Chenoweth Run # 1 at Ruckriegal Parkway	F	75

Table 6-3 Calibration Statistics for TN for USGS WQ Calibration and MSD Validation Stations utilized in the Floyds Fork model

Station	Station Name	Simulated			Measured			Difference		
		Mean	5 %tile	95 %tile	Mean	5 %tile	95 %tile	Mean	5 %tile	95 %tile
Location : Main Stem, Floyds Fork										
03297830	Floyds Fork at Highway 53	0.99	0.54	1.65	1.16	0.30	3.73	-0.18	0.24	-2.08
03297845	Floyds Fork near Crestwood	0.90	0.50	1.38	1.37	0.41	4.56	-0.47	0.09	-3.18
03297900	Floyds Fork near Peewee Valley	3.83	1.17	12.29	4.08	0.72	8.51	-0.25	0.45	3.79
03297930	Floyds Fork at Echo trail bridge	3.43	1.17	9.12	3.92	2.12	9.46	-0.49	-0.96	-0.34
03298000	Floyds Fork at Fisherville	3.08	1.13	8.38	2.77	1.49	6.21	0.31	-0.36	2.17
03298120	Floyds Fork at Seatonville Road	2.74	1.09	7.29	1.29	0.41	3.17	1.45	0.69	4.12
03298200	Floyds Fork near Mt. Washington	3.27	1.15	8.10	3.54	1.47	7.86	-0.28	-0.32	0.23
03298470	Floyds Fork near Shepherdsville	3.07	1.16	7.33	2.18	1.03	4.61	0.88	0.13	2.73
EFFFF001	Floyds Fork at Ash Avenue	3.83	1.17	12.29	2.29	0.00	0.00	1.54	1.17	12.29
EFFFF002	Floyds Fork at Bardstown Road	3.27	1.15	8.10	2.71	0.00	0.00	0.56	1.15	8.10
EFFFF003	Floyds Fork at Old Taylorsville Road	3.08	1.13	8.38	2.39	0.00	0.00	0.69	1.13	8.38
Location: Tributaries										
03297850	South Fork Curry's Fork at Moody Lane	3.32	0.96	7.33	8.39	1.76	18.55	-5.07	-0.80	-11.22
03297855	South Fork Curry's Fork at Highway 393	1.97	0.96	5.23	1.05	0.41	2.42	0.92	0.55	2.81
03297860	North Fork Curry's Fork at Stone Ridge road	8.58	1.56	20.10	15.26	2.63	30.05	-6.69	-1.08	-9.95
03297875	Ashers Run at Abbott lane near Crestwood	0.80	0.44	1.26	1.31	0.00	0.00	-0.51	0.44	1.26
03297880	Currys Fork near Crestwood	5.66	1.29	15.76	5.99	1.18	17.24	-0.33	0.11	-1.48
03297950	Long Run at Old stage coach road	0.72	0.40	1.16	0.67	0.00	0.00	0.05	0.40	1.16
03297975	South Long Run at Hobbs Lane	0.82	0.46	1.33	0.83	0.24	2.10	-0.01	0.22	-0.77
03297980	Long Run near Fisherville	0.81	0.47	1.28	1.01	0.27	3.05	-0.21	0.20	-1.77
03298005	Pope lick at South poope lick road near Fisherville	1.05	0.66	2.01	0.59	0.24	1.80	0.46	0.42	0.21
03298020	Cane Run at Thurman Road	0.86	0.51	1.10	1.07	0.00	0.00	-0.21	0.51	1.10
03298100	Pope lick at pope lick road near Middletown	1.85	0.56	3.80	0.77	0.23	1.82	1.08	0.33	1.98
03298110	Pope lick at Rehl road near Fisherville	0.66	0.46	0.91	0.59	0.24	1.72	0.08	0.22	-0.81
03298135	Chenoweth Run at Ruckriegal Parkway	2.14	0.99	3.43	0.95	0.32	2.12	1.19	0.67	1.31
03298138	Chenoweth Run at Jeffersontown STP at Jeffersontown	8.29	1.79	15.98	18.62	10.26	34.30	-10.33	-8.48	-18.32
03298150	Chenoweth Run at Gelhaus Lane near Fern creek	7.12	1.58	13.93	12.46	2.55	20.72	-5.34	-0.97	-6.79
03298160	Chenoweth Run at Seatonville road near Jeffersontown	6.68	1.49	13.17	10.03	2.08	18.96	-3.35	-0.59	-5.80
03298250	Cedar Creek at Thixton Road	4.05	1.03	7.34	4.58	2.06	7.66	-0.53	-1.03	-0.31
03298300	Pennsylvania Run at Mt. Washington	2.26	0.90	5.42	4.09	0.54	14.60	-1.83	0.36	-9.19
EFFCR001	Chenoweth Run # 1 at Gelhaus Lane	7.12	1.58	13.93	8.77	0.00	0.00	-1.65	1.58	13.93
EFFCR002	Chenoweth Run # 1 at Ruckriegal Parkway	2.14	0.99	3.43	4.07	1.30	18.80	-1.93	-0.31	-15.37

Table 6-4 Calibration Statistics for TP for USGS WQ Calibration and MSD Validation Stations utilized in the Floyds Fork model

Station	Station Name	Simulated			Measured			Difference		
		Mean	5 %tile	95 %tile	Mean	5 %tile	95 %tile	Mean	5 %tile	95 %tile
Location : Main Stem, Floyds Fork										
03297830	Floyds Fork at Highway 53	0.16	0.02	0.49	0.15	0.04	0.37	0.01	-0.02	0.12
03297845	Floyds Fork near Crestwood	0.10	0.02	0.26	0.38	0.05	2.05	-0.28	-0.02	-1.79
03297900	Floyds Fork near Peewee Valley	0.56	0.06	1.48	0.58	0.13	1.29	-0.03	-0.07	0.18
03297930	Floyds Fork at Echo trail bridge	0.55	0.07	1.46	0.29	0.11	1.90	0.27	-0.04	-0.44
03298000	Floyds Fork at Fisherville	0.50	0.06	1.36	0.18	0.08	0.65	0.32	-0.02	0.71
03298120	Floyds Fork at Seatonville Road	0.44	0.07	1.20	0.14	0.04	1.03	0.31	0.03	0.17
03298200	Floyds Fork near Mt. Washington	0.39	0.08	0.90	0.14	0.04	0.41	0.24	0.04	0.49
03298470	Floyds Fork near Shepherdsville	0.43	0.08	1.06	0.19	0.06	0.45	0.24	0.02	0.61
EFFFF001	Floyds Fork at Ash Avenue	0.36	0.06	1.16	0.28	0.04	0.80	0.08	0.02	0.36
EFFFF002	Floyds Fork at Bardstown Road	0.29	0.08	0.76	0.16	0.04	0.39	0.13	0.04	0.37
EFFFF003	Floyds Fork at Old Taylorsville Road	0.34	0.06	1.03	0.18	0.04	0.57	0.16	0.03	0.46
Location: Tributaries										
03297850	South Fork Curry's Fork at Moody Lane	1.48	0.12	2.77	2.25	0.27	3.41	-0.77	-0.15	-0.64
03297855	South Fork Curry's Fork at Highway 393	0.83	0.07	2.19	0.20	0.03	0.66	0.63	0.04	1.54
03297860	North Fork Curry's Fork at Stone Ridge road	0.54	0.08	1.04	1.95	0.25	3.80	-1.41	-0.17	-2.76
03297875	Ashers Run at Abbott lane near Crestwood	0.06	0.02	0.11	0.13	0.00	0.00	-0.07	0.02	0.11
03297880	Currys Fork near Crestwood	0.56	0.07	1.24	0.72	0.15	2.09	-0.16	-0.08	-0.85
03297950	Long Run at Old stage coach road	0.06	0.02	0.13	0.07	0.00	0.00	-0.01	0.02	0.13
03297975	South Long Run at Hobbs Lane	0.06	0.02	0.14	0.20	0.06	0.74	-0.13	-0.04	-0.60
03297980	Long Run near Fisherville	0.07	0.02	0.14	0.17	0.03	0.79	-0.10	0.00	-0.64
03298005	Pope lick at South poope lick road near Fisherville	0.11	0.02	0.21	0.05	0.01	0.24	0.06	0.01	-0.03
03298020	Cane Run at Thurman Road	0.10	0.04	0.18	0.20	0.00	0.00	-0.10	0.04	0.18
03298100	Pope lick at pope lick road near Middletown	0.13	0.02	0.24	0.07	0.02	0.30	0.06	0.01	-0.06
03298110	Pope lick at Rehl road near Fisherville	0.07	0.02	0.14	0.05	0.01	0.23	0.02	0.01	-0.09
03298135	Chenoweth Run at Ruckriegal Parkway	0.09	0.03	0.14	0.03	0.01	0.14	0.06	0.02	0.00
03298138	Chenoweth Run at Jeffersontown STP at Jeffersontown	0.41	0.17	0.69	0.88	0.20	2.18	-0.46	-0.02	-1.49
03298150	Chenoweth Run at Gelhaus Lane near Fern creek	0.42	0.14	0.74	0.44	0.09	1.56	-0.02	0.05	-0.82
03298160	Chenoweth Run at Seatonville road near Jeffersontown	0.41	0.14	0.72	0.36	0.06	1.09	0.04	0.08	-0.37
03298250	Cedar Creek at Thixton Road	0.38	0.08	0.92	0.34	0.03	1.17	0.04	0.05	-0.25
03298300	Pennsylvania Run at Mt. Washington	0.70	0.04	2.04	0.87	0.06	2.24	-0.17	-0.02	-0.20
EFFCR001	Chenoweth Run # 1 at Gelhaus Lane	0.43	0.13	0.86	0.38	0.04	1.66	0.05	0.09	-0.80
EFFCR002	Chenoweth Run # 1 at Ruckriegal Parkway	0.08	0.03	0.12	0.15	0.02	0.58	-0.08	0.01	-0.46

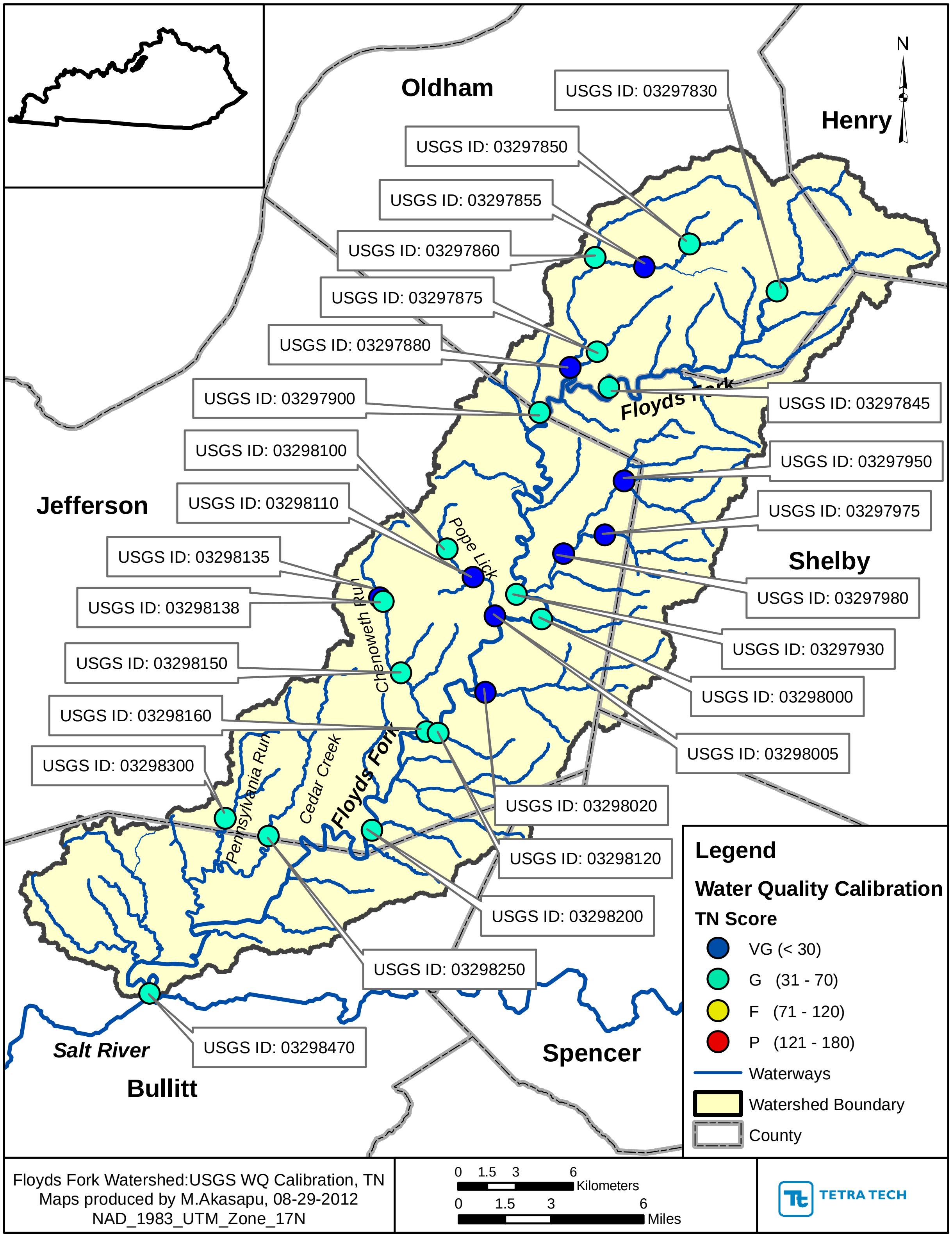

Figure 6-1 Qualitative scores of the USGS WQ Calibration stations for TN

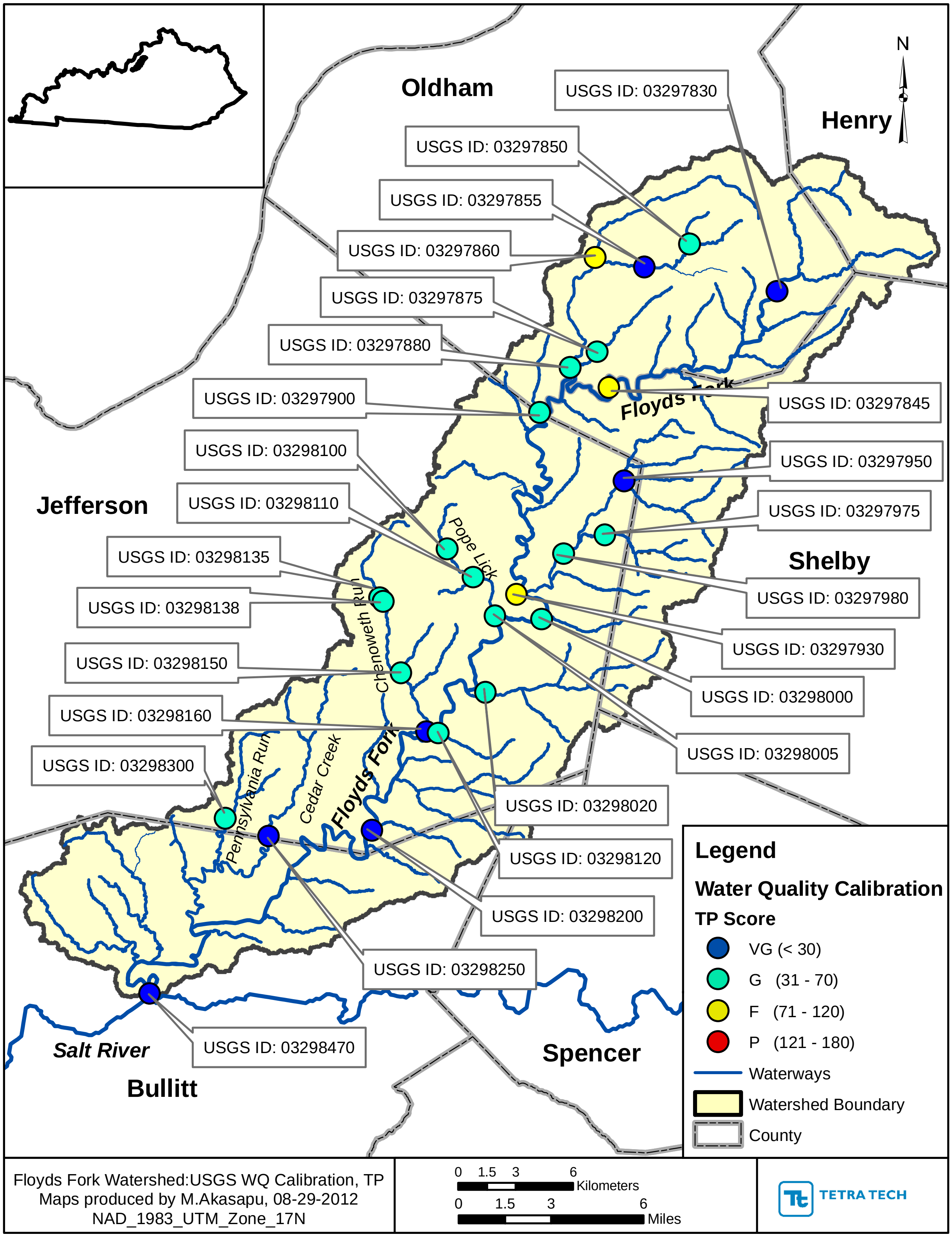

Figure 6-2 Qualitative scores of the USGS WQ Calibration stations for TP

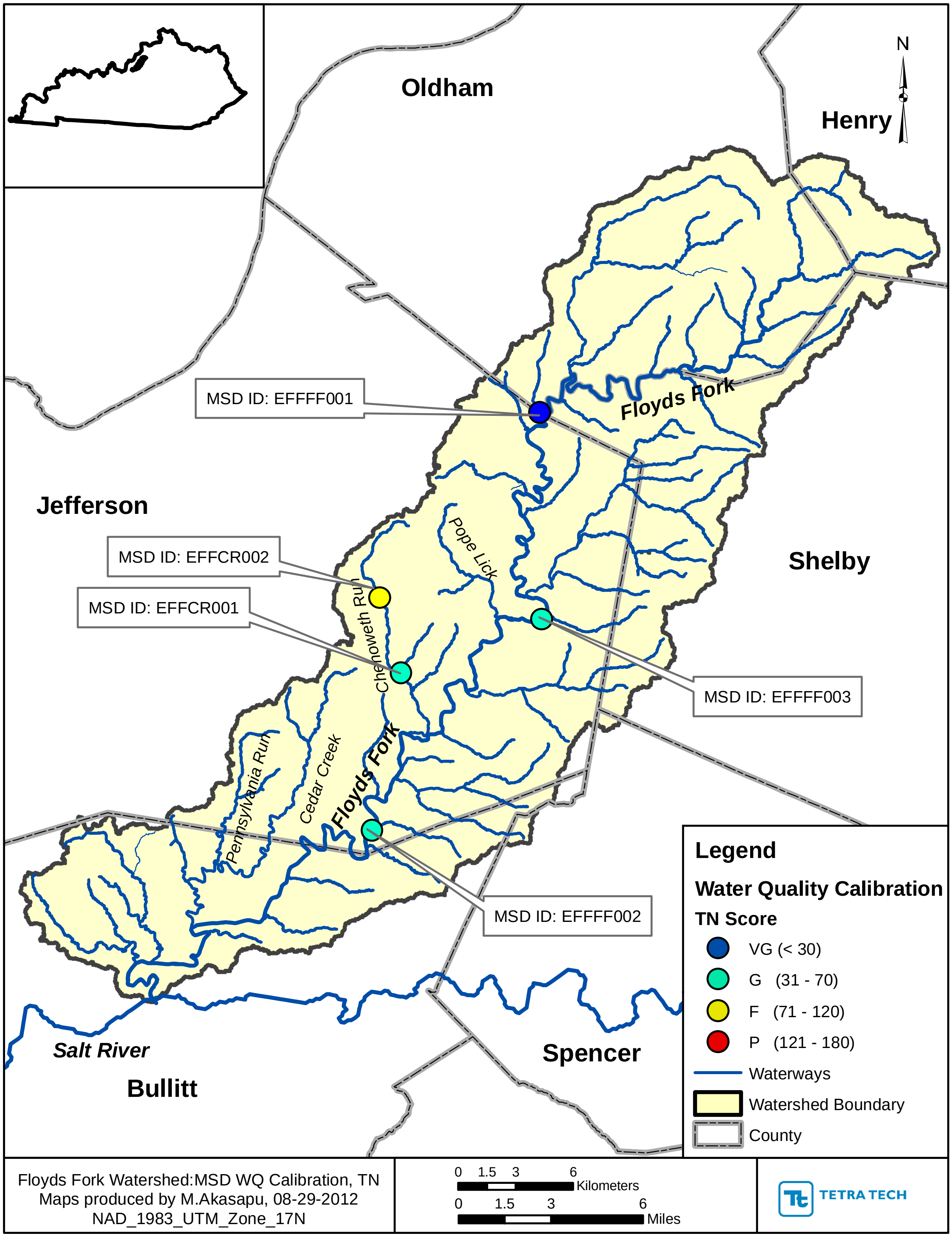

Figure 6-3 Qualitative scores of the MSD WQ Calibration stations for TN

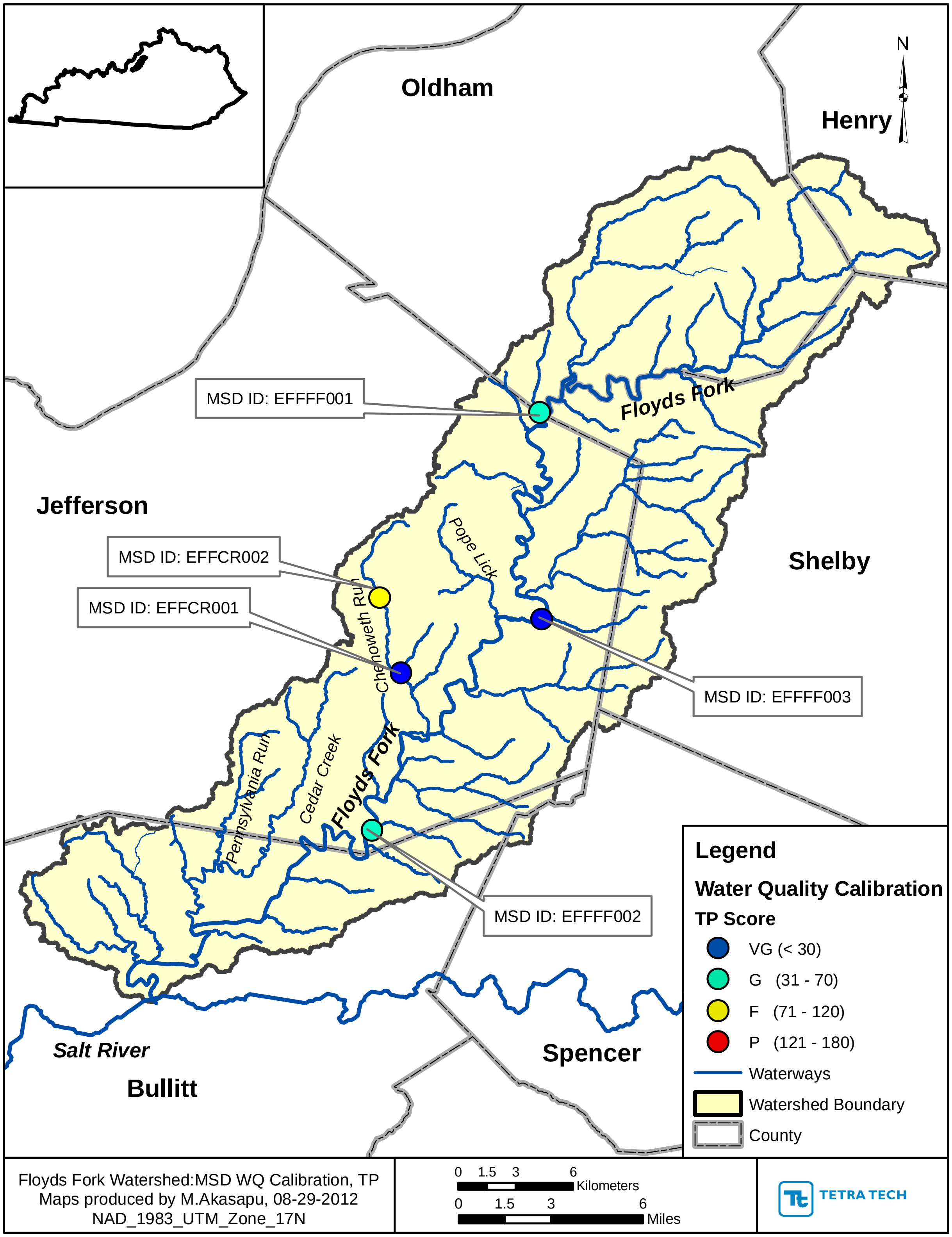

Figure 6-4 Qualitative scores of the MSD WQ Calibration stations for TP

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